SSI Report 8505-5

ORNL/Sub 85-05923/1

(2)

EVALUATION OF PRODUCTION PROCESSES TO IDENTIFY ESSENTIAL EQUIPMENT

by

A.B. Willoughby, C. Wilton, and J.V. Zaccor

FINAL REPORT

June 1986

for

FEDERAL EMERGENCY MANAGEMENT AGENCY

and

OAK RIDGE NATIONAL LABORATORY

Subcontract Number 62X-05923C

SCIENTIFIC SERVICE, INC. REDWOOD CITY, CALIFORNIA 94062

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ORNL/Sub/85-05923/1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF PRODUCTION PROCESSES TO IDENTIFY ESSENTIAL EQUIPMENT		5. TYPE OF REPORT & PERIOD COVERED Final Report 6. PERFORMING ORG. REPORT NUMBER SSI 8505-5
7. AUTHOR(s) A.B. Willoughby, C. Wilton and J.V. Zaccor		8. CONTRACT OR GRANT NUMBER(s) EMW-84-1729 Subcontract 62X-05923C
9. PERFORMING ORGANIZATION NAME AND ADDRESS Scientific Service, Inc. 35 Arch Street, Redwood City, CA 94062		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Federal Emergency Management Agency Washington, D.C. 20472		12. REPORT DATE June 1986 13. NUMBER OF PAGES 246 pages
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Oak Ridge National Laboratory Oak Ridge, TN 37831		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

countermeasures; disaster preparedness; essential equipment; industrial processes; nuclear attack; protection plan; user's manual; vulnerability assessment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report describes a method to identify items of equipment essential to industrial processes, rank their relative importance, assess their vulnerabilities to critical damage mechanisms common among hazards, and tie this to a single index. The method is formatted as worksheets that industry can apply to facilitate and organize selection of countermeasures to enhance physical and economic survival in a major disaster.

An assessment of the procedure applied to nuclear attack is described. Both technical and practical aspects of procedure viability are addressed, and testing of both

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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Block 20 (contd)

aspects are discussed. Notwithstanding gaps identified in technical knowledge for protecting industrial equipment from a nuclear attack, and recommendations for experiments to fill these gaps, a procedure is described that appears workable; three case histories are presented. The examples address the identification of essential equipment, assessment of its vulnerability, establishment of the threat magnitude to use for planning, and identification of suitable countermeasures to meet the threat. With addition of threat and magnitude for other hazards, the procedure appears suitable for multi-hazard application.

The five-part report ends with a user's manual industrial personnel can apply, and worksheets to complete, that will constitute an equipment protection plan summary.

(DETACHABLE SUMMARY)

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Work Performed For
Federal Emergency Management Agency
Washington, D.C. 20[illegible]
Interagency Agreements DOE [illegible]1197-81
and FEMA EMW-84-172[illegible]

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
Under Contract No. DE-AC05-840R21400

(DETACHABLE SUMMARY)

EVALUATION OF PRODUCTION PROCESSES TO IDENTIFY ESSENTIAL EQUIPMENT

This report presents the results of a program to develop a simple methodology that industry can use to: identify essential equipment, rank it for relative importance, estimate equipment vulnerabilities, select appropriate hardening options for equipment protection. The procedure developed is formatted to provide a concise equipment-protection-plan summary.

Intermediate tasks required for this study included: a review of equipment damage mechanisms and vulnerability, identification of principal damage parameters, development of simplified vulnerability assessment procedures, identification and development of protective countermeasures, evaluation of the technical and practical feasibilities of procedures and countermeasures, identification of gaps in technical knowledge regarding effects of nuclear weapons on industrial equipment, and recommendations for studies to fill these gaps. Technical feasibilities were assessed by comparison of the procedure outcome with field test data and practical feasibilities were assessed by means of three case histories.

From the study it is concluded that the procedure appears both concise and workable, insofar as data exist to assess this. As required, technical gaps that would affect hardening methods and decisions for a nuclear attack threat have been identified; these require additional field experiments to provide answers. To be appropriate, the experiments must subject industrial equipment to one or more large scale simulations, such as MINOR SCALE and the forthcoming MISTY PICTURE. Additional applications assessments, particularly involving industry applications support programs, are recommended prior to drawing conclusions about practical applicability; three case histories are scarcely enough to supply an answer. There are many dozens of different kinds of industries, let alone variation from plant to plant within one kind of industry, that ought to be evaluated prior to considering promulgating guidance based on the limited applications evaluation.

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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes--Printed Copy A11 Microfiche A01

FOREWORD

This report presents the results of a program conducted for the Oak Ridge National Laboratory (ORNL) by Scientific Service, Inc. (SSI) on the Evaluation of Production Processes to Identify Essential Equipment. Funding for this program was provided by the Federal Emergency Management Agency (FEMA).

> The objective of this program, stated in the work statement, follows: "The purpose of this effort is to identify a planning process and systematized information which can be used by industrial planners to prioritize and categorize their production equipment for survival and recovery. This process will be approached by generalizing the problem, applying the results to specific situations, evaluating the results, and then redefining and producing guidance for application advice to industry. This application and advice for critical equipment identification would take the form of instructions on hardening techniques, cannibalization of other equipment, etc."

This program was an integral part of a series of programs conducted by FEMA to develop guidance for businesses and industries to plan for disasters, whether they be natural, technological, or nuclear. There is a complete spectrum of planning possibilities, but for discussion purposes, consider only the following three levels:

1. In-place protection of either an operating or a shutdown facility: This is the most comprehensive state and one that would allow either the continued operation of a facility during a disaster or attack, or the immediate resumption of activities of a shutdown facility after such events. This level of protection, however, is very difficult and expensive to achieve in most cases and depends heavily on location of the facility, relative to possible threats.

2. Protection of essential elements: This is probably the most practical of conditions from a cost/benefit point of view in that it assumes some losses from a disaster but assures that the essential elements required for resumption of activities survive.

3. Recovery-only: This is a minimal type of plan. It is based on the strategy of accepting heavy damage, even possible destruction of the facility, depending entirely on capital recovery to rebuild. Such planning strategy is typical of many businesses that choose to limit their disaster planning mainly to the purchase of fire (and sometimes earthquake and flood) insurance and to meeting life-safety requirements in the law. Inherent in this strategy is a flawed presumption; i.e., that the disaster does not affect the general supply of recovery resources. This is surely **not** the case in a nationwide disaster. As an international strategy, the concept might work, assuming the United States were a net creditor; as a debtor, the capability to reimburse for goods acquired, post disaster, would be seriously affected. Self-reliance is preferred.

From a practical standpoint, the guidance being developed for FEMA (see, for example, Ref. 1) is directed toward assisting business and industry to achieve at least Level 2 types of plans and for special facilities such as ones with emergency response or national security functions a Level 1 type of plan. To develop the guidance for these plans requires the development of techniques to: give credence to changes in priorities brought about by a national disaster, identify essential equipment, assess the vulnerability of classes of essential equipment, identify or develop hardening methods, and test or verify these techniques and methods in industry (i.e., assess the material developed under this program).

The program called for development, first, of a generalized approach for prioritizing and categorizing essential **equipment** followed by a test of applicability to three different essential **processes**. There are a number of reasons for this approach over one that looks exclusively at essential industries. For example, factors that required consideration included the following:

- Aside from some obvious emergency response and national security organizations, it is difficult to identify, positively, many of the industries that might be truly essential because determining whether an organization is essential frequently depends on the type and seriousness of the disaster. An even-handed approach, involving critical equipment instead, will bypass the trap of requiring essential and non-essential **industries** to be identified in favor of identifying essential processes.

- o After a major disaster, a great deal of substitution of processes and equipment will most likely be necessary. It is expected also that priorities will change so that it will be difficult, if not impossible, to identify specific substitution requirements because they will depend on the type and level of disaster, and on new priorities.

- o Because it is anticipated that industry and businesses will have to bear the major cost and effort in the disaster planning and recovery process it seems also desirable to treat industries impartially and have a planning process that virtually any industry can apply; an additional rationale for this is that the more equipment available post-event, the better the chance that the recovery will be rapid following a major disaster.

- o Given a national disaster, recovery might be enhanced by switching non-critical industries (determined after the fact) to production of more essential items, or by scavenging equipment that survived in some non-critical industry in order to use it in some very essential industry (at the time). Though it is quite possible that items selected as "essential to (some) production" in a non-critical industry would not be the same as those selected as "essential to national survival," non-critical processes (those that can be ignored) are likely to be similar in all companies (cosmetic processing and packaging to enhance marketing; attaching company ID) so long as the scenario for the circumstance is much the same.

To summarize the approach: the effort under this program ignores the age-old, moot question of essential industries and concentrates on some procedures and guidance that plant personnel might use both to identify those items of equipment and the processes **in their plant** that are truly essential for the facility's survival and recovery and to enable them to select appropriate ways to protect these. Two additional aspects of the effort were to identify types of equipment for which additional data on protection may be required and items that may be so unprotectable as to require something such as stockpiling for an alternative. These latter two items are presumably not for the purpose of informing industry but for further program efforts in a subsequent study.

The need for industrial production survival guidance stems from two factors: time for action will be severely limited, and earlier studies conducted and reported by SSI have provided evidence that the equipment absolutely necessary for basic production has been typically overstated. One of the most difficult aspects for industry and business owners and managers to appreciate in planning for a disaster is determining what really is essential under a changed set of priorities. Principally, this appears to derive from a reluctance or inability to conceive a situation in which a totally different set of priorities would establish requirements. Typically, in answer to the question of what is absolutely essential to the production operation the response will be: "Everything, or else we wouldn't have it." This response may be reconsidered and altered, however, if a suitable scenario is postulated. For example, the following one has proved effective:

- o A major disaster (a hurricane, or nuclear war) is expected to strike your facility within the next 24 to 72 hours,
- o You have a day or two to protect or evacuate the equipment that will be needed to return your facility to some level of production after the disaster,
- o You won't have enough time to protect or evacuate all the equipment.

Now, what equipment would you select?

The answer to this varies considerably. Generally, it tends to depend on the magnitude of the disaster the respondent is able to visualize (which can often be improved with dialogue). Essentially, what is seen as critical depends on how much outside help seems likely to be available (which varies widely depending on whether the survival problem is local, regional, or national in scope) and **attitude**. Clearly, what **appears** critical to the planner depends very heavily on personal attitude as well as on an appreciation of the circumstances.

Scientific Service, Inc., has applied the above scene-setting technique in previous studies on guidance. The process produced varied and interesting results; an example noted was a canner of tomatoes in San Jose, California. Here, the owner's son responded to the question of what was really essential with the answer quoted above. Questions about each piece of equipment and its purpose, however,

revealed that, while many items improved efficiency and profit, they were not an absolute requirement for production; the participant finally came to realize that only a few specific items would be required to continue production. Moreover, after some further thought, an even more startling statement was made: "In a real emergency the **entire plant would be unnecessary** because tomatoes are just condiments and have little nutritional value. We could, however, use our boiler and evaporator to process milk, meat, or other products that would be more essential." Here, then, is an attitude that is truly altruistic and a response that is broad in scope.

A similar end result response for a facility of totally different nature came from the manager of a large utility-transformer manufacturer who, after some thought, decided that following a major disaster the most critical job would be the repair of transformers, rather than their manufacture. For this critical task, the most essential equipment would be welders, portable generators, and hand tools. The other 95% of the facility would not be needed. The employees with the expertise would, of course, become a very essential resource to protect as well.

Additional responses in a similar vein for a variety of facilities have been noted by the SSI staff over the last two decades of continued involvement with, and work on, industrial protection. These experiences were obtained through establishment of personal contact and rapport with businesses and industries willing to give thoughtful consideration to the problem. Basically, since inception, what has been required in this program has been development and evaluation of a planning process and systematized information development that industrial planners throughout the country could apply to prioritize and categorize their production equipment for survival and recovery. What was developed initially constituted a multistep process that assisted the planner in including concerns for equipment essential to the facility's production via a facility-specific disaster response plan. The first stage philosophy was geared to considering only the facility's survival--to produce the same products--and the methods that might help industry to achieve this goal. Following industry participation in evaluation of the guidance, it became clear that scenarios should involve broader evaluations of what survival means or entails (particularly when the event is a nuclear attack). Some industries that gave this subject consideration developed plans that involved switching their line of business or their product list. Sometimes the change was to achieve greater independence, and sometimes it was to provide a product to serve the immediate situation. Eventually, it will be necessary to consider and incorporate such factors into planning guidance.

Part I of this report presents a discussion of the general nuclear weapon threat and factors and steps that are involved in industrial survival planning. Part II presents a summary of the technical effort performed during the project in the area of quantitative assessments of vulnerability. These include: developing methods for predicting the vulnerability of industrial equipment to nuclear weapon effects; determining the degree of protection afforded by various protection methods; and compiling simplified procedures for the development of industrial protection plans. Also included in Part II is a recommended test program designed to fill in the gaps in technical knowledge of the response of industrial equipment to nuclear effects, and the effectiveness of countermeasures.

Part III summarizes case histories involving the application of Parts II and V. This segment was undertaken to identify gaps in knowledge of industrial response that cause limitations stemming from applications impracticalities. An emergency services facility requiring a Level 1 protection effort and industrial facilities requiring a Level 2 protection effort are discussed.

Part IV presents conclusions and recommendations.

Part V of this report is an applications manual for use by plant personnel. It gives the simplified procedures for evaluating equipment vulnerability and developing protection plans.

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PART I

THREAT ASSESSMENT AND PROBLEM DEFINITION

PART I

Section 1
INTRODUCTION

The steps required to identify and protect critical equipment are indicated in Figure I-1. In this section of the report the first two steps in the process will be discussed: the Facility, and Threat Identification. Equipment Inventory and Essentiality Rating Procedure are discussed in Section 2. The Vulnerability Analysis and Protection/Hardening Alternatives are discussed in Part II of the report.

FACILITIES

As noted in the Foreword, a generalized approach is desired that will be applicable to almost all business and industry facilities, rather than concentrating on specific industries that might be considered essential for one reason or another. The rationale for this approach has been given already. Under this broader approach, the procedures given can be used by business and industry owners and managers whether they are a small store, a bank, or a large industrial complex.

The program requirements also place emphasis on equipment protection. It is obvious, however, that overall facility protection requires other activities to be considered, e.g., emergency response planning and hazards generated by secondary effects (fires, hazardous materials spills or releases, power outages). These complementary activities are addressed under a companion effort being conducted by Scientific Service, Inc. (Ref. 1).

DESCRIPTION OF THREATS

Vulnerabilities of critical resources (people and equipment) are not independent of the hazards because of the very different threats these can pose. For example, consideration of a number of the threats posed by a fire hazard (burning, cremating, suffocating, asphyxiating, anoxia, hypothermia, poisoning by CO, CO_2, toxics,

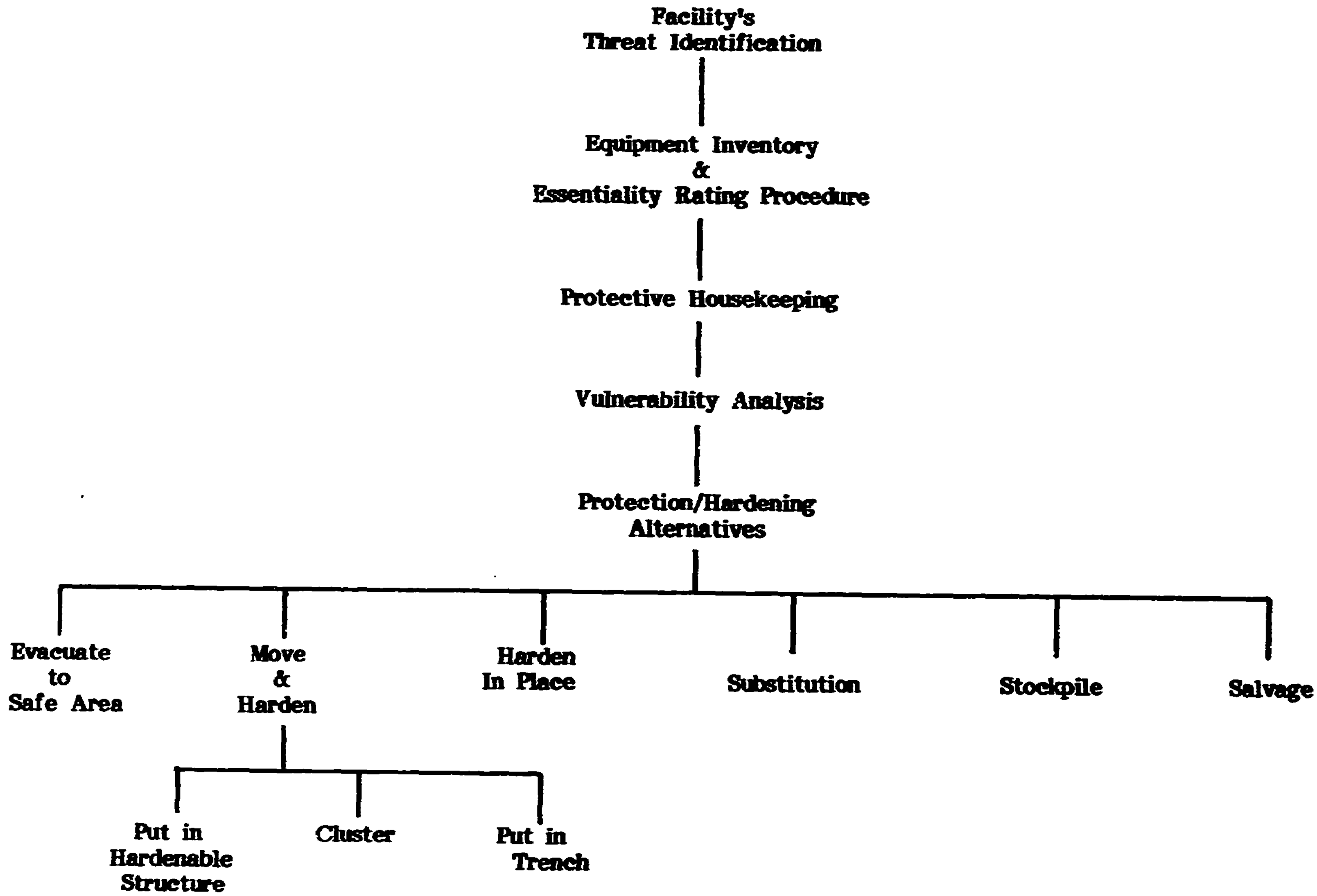


Fig. I-1. Steps to Identify and Protect Critical Equipment.

melting, charring) shows that they are almost all different from those posed by a flood (pressure and impact damage, contamination, corrosion, erosion, drowning). The consequence of this variability in threats is that specific protective measures may be expected to be different as well. Even though it may be said that there are essentially only two ways to deal with threats, i.e., be somewhere else, or have an adequate shelter, in the final analysis the **specifics** of these two **functional** responses are clearly dependent on the hazards and threats posed. Obviously, **where** a threat occurs, its **range**, and the **time** required to move to somewhere else that will prove safe, are significantly different when the threat is a fire from when it is a hurricane or a nuclear attack.

The one invariant in the picture is that within a facility the resources critical to production do not change with threat (they are pretty much fixed by the production process). In time of need, however, resource availability from outside the facility can change drastically with threat; as the size of the area damaged increases, resources from outside to support recovery in the damaged area decrease. Clearly, if a national disaster occurs, recovery support from other parts of the nation becomes unlikely. The disaster most likely to reach national proportions (leaving most major regions on their own) is a nuclear attack. It is here where major attention needs to be focused, and the result will have broad application to other events. For example, nuclear blasts will trigger many incidences of familiar smaller scale disasters: hazardous materials spills, building damage, fires. Moreover, the blast wave is a damage mechanism much like that for hurricanes, tornadoes, floods, and areawide storms; i.e., they all involve damage caused by high velocity winds plus impacts of heavy masses (e.g., water, collapsing structures, objects set in motion by wind and wave motion). Hence, a method for dealing with the blast wave from a nuclear threat and impacts from objects set in motion by this major **national** threat will also protect against hurricanes, tornadoes, severe storm winds, and impact damage from floods.

DESCRIPTION OF THE MAJOR NATIONAL THREAT

As will be shown in Part II of the report, with proper planning it is possible to protect industrial equipment so that it can even survive a nuclear attack. Because most business and industrial people (indeed, many planners today) are totally ignorant of the consequences of a nuclear blast, it is desirable to describe for guidance

purposes what the effects might be. This scene setting is particularly important as a means to trigger appreciation for critical shifts in priorities, which has been identified as having a large impact on defining essential equipment. What needs to be imparted in such scene setting is something that will quickly identify what can happen and what damage mechanisms must be dealt with for industrial survival, as well as an indication that survival is possible, e.g., as provided in Part V.

Section 2
INVENTORY OF ESSENTIAL EQUIPMENT

INTRODUCTION

A specific task under this program was the development of a format that could be used for a range of peacetime and wartime hazards to identify and localize potential weak links in production processes and their associated hardware. The RFP indicated that this format was to be developed for at least three critical industrial processes. As the Foreword indicated, the approach chosen has been to develop a format that could be used by all industries. The rationale is that the more facilities able to take action, the larger the reservoir of surviving equipment to speed recovery. With this rationale and approach, focusing on critical processes within critical industries was not important until the in-plant testing of the format was conducted. Then it would be prudent to demonstrate applicability in an essential facility (see Part III).

Before taking up the subject of formats for determining the essential equipment in a process, it might be useful to discuss a practical methodology for arriving at those elements of an industrial facility that are essential to output. The quickest route is to begin with an elimination process. In the first step, general facility operations are broken down by types. Among these different types of operations will be some that are quickly recognizable as not critical during a crisis period (because of changed priorities), i.e., there will be operations that can be closed down or ignored for a period of weeks (or longer). Among the remaining operations, further analysis may be required to determine if there are others whose purpose have questionable importance to immediate survival of a production capability. To provide an example, a typical industrial facility might have departments, groups, divisions, etc., that would execute the following operations:

Security	Personnel	Maintenance
Accounting	Safety	Public Relations
Purchasing	Quality Control	Marketing & Sales
Shipping	Utilities	Transportation/Dispatch
Receiving	Production	

At the next step, these operations are organized according to some kind of rating system that clearly identifies which operations require no further analysis to warrant discontinuing them altogether for now. A typical classification for the second step might be as follows (though classification schemes may vary from plant to plant and by type of operation):

1. Necessary on a day to day basis to produce the basic product or service of the company (Examples - Production, Utilities)

2. Necessary infrequently to produce the product or service of the company (Examples - Purchasing, Receiving, Quality Control, Maintenance)

3. Not necessary but has equipment and/or personnel that will be valuable for emergency response (Examples - Transportation, Shipping, Non-production Personnel, Safety)

4. Necessary in the long term but can be shut down temporarily (Examples - Accounting, Security, Marketing and Sales, Public Relations)

By this process large segments (e.g., the operations under items 2 and 4) can be identified as not actually requiring an essential processes and equipment analysis. In this procedure, one must be careful not to overlook some items of equipment that may be necessary to initiate postdisaster recovery but that are not immediately vital for production. Typical examples of this sort of item might be: medical equipment, maintenance equipment and spare parts, rigging and repair equipment, communications equipment. Thus, Security and Maintenance may have exactly the kind of equipment and tools that would be most useful in a recovery period and that should be a high priority to remove to a low risk evacuation area for that purpose.

SELECTION OF FORMAT

Three formats were available as candidates for inventorying essential equipment: one was included as part of the RFP, a second was presented in Ref. 4, and a third is a format developed by SSI and presented in Refs. 1 and 5.

Before discussing selection of a format, it is useful to define desirable features. A format is desired that:

- o Allows rapid analysis of a production process to determine the elements that are essential (likewise, nonessential);
- o Is designed so that the process can be conducted by as few people as possible (one or two at most);
- o Has sufficient information on the data collection form for the surveyor to make the necessary decisions as to what type of data to collect and how to assess the role of each item of equipment (i.e., essential or nonessential in the process);
- o Is designed such that only absolutely necessary information is requested;
- o And, if possible, uses a data collection form that, when completed, becomes part of an overall disaster response plan for the industrial facility without requiring the data to be transferred to other forms.

The first format (included in the RFP and apparently developed by Engineering and Economics Research, Inc.), is presented in Figures I-2 through I-9. This format consists of eight pages of data sheets, labeled as follows: Facility Summary Sheet, Primary Product Data Sheet, Secondary Product Data Sheet, Equipment Data Sheet, Building Data Sheet, Critical Input Materials, Expedient Protection Data, and Facility Utility Data. A review of this format reveals that the assemblage of data does not meet most of the requirements itemized above. An inordinate amount of data is requested (much of which would be proprietary so that release would be unacceptable to most industries); little of the assemblage is useful for the evaluation of production processes to identify essential equipment; there is considerable redundancy with the same data entered several times (utility data for example); and there is no clear picture of how the data forms fit into an overall disaster response plan format. The one form that tends to collect some of the necessary data is the Equipment Data Sheet, Figure I-5. This form does collect size and weight information but also requires a vast amount of information that either is not required for determining if the equipment is essential, or is a waste of effort until an analysis is completed to

FACILITY SUMMARY SHEET

Date ________________

Analyst ______________

Section ______________

Page ____ to ____

Facility SIC #: ____________ Date of Visit: ____________________

Facility Name: ____

Address: ____

City ___________________________ State _______ Zip Code __________

Phone #: (   ) ____________

Contact Person: ____

Plant Manager: ____

Products

Description	SIC #	Annual Shipments
		$
		$
		$
		$
		$
		$
	Total	$

Total No. Employees ___________

Figure I-2

PRIMARY PRODUCT DATA SHEET

Date ______________

Analyst ___________

Section ___________

Page ___ to ___

Facility: ____

SIC #: _____________

Product Description: ____________________________________

Annual Shipments: ___ ___________

Capital Investment: ________________

Annual Value Added: ________________

Average Wage + Benefits $/hr: _____________

No. of Employees: ____Manufacturing____Maintenance____Administrative____

Total _______

Manufacturing: hrs/wk ____ Present _____ Maximum _____

Normal Production Capacity $/yr: _____________

Maximum Possible Production Rate Multiplier: ___________

Min. Production Rate (Percent of maximum capacity): ___________

No. of Production Lines: ______ Capacity Choke Point: _______

Annual Energy Use:

electricity kWh ________ peak elect. demand kW ________

primary fuel ______ units __________ quantity/yr ____________

secondary fuel _______ units ________ quantity/yr ___________

dual fuel capability ___Y or ___N dual fuel possibility ___Y or ___N

Annual cost of energy inputs $_______ Annual value of material inputs $______

Avg. site product inventory value $__________

Critical input materials for this product ___________________________

____

Comments: ____

____

Figure I-3

SECONDARY PRODUCT DATA SHEET

Date ______________

Analyst ____________

Section ____________

Page ____ to ____

Facility: ____

SIC #: ______________

Product Description: ____________________________________

Annual Shipments: __________________

Capital Investment: _________________

Annual Value Added: _________________

Average Wage + Benefits $/hr: ______________

No. of Employees: ____Manufacturing ____Maintenance ____Administrative

Total _______

Manufacturing: hrs/wk______ Present______ Maximum______

Normal Production Capacity $/yr: ______________

Maximum Possible Production Rate Multiplier: ___________

Min. Production Rate (Percent of maximum capacity): ___________

No. of Production Lines: ______ Capacity Choke Point: _______

Annual Energy Use:

electricity kWh ________ peak elect. demand kW ________

primary fuel ______ units __________ quantity/yr ____________

secondary fuel _______ units ________ quantity/yr ___________

dual fuel capability ___Y or ___N dual fuel possibility ___Y or ___N

Annual cost of energy inputs $_______ Annual value of material inputs $______

Avg. site product inventory value $__________

Critical input materials for this product ___________________________

____

Comments: ____

____

Figure I-4

EQUIPMENT DATA SHEET

Date ________________

Analyst ______________

Section ______________

Page ____ to ____

Facility: ____________________________________ SIC #: ________

Equipment: Name ____

End Product Produced __________________ Quantity ______
Priority __1__2__3

Unit Weight __________ Dimensions _______H, _______W, _______L

Criticality to site: Essential ____ No substitute on site ____

Substitute on site ____ Optional ____

Portability: As is ____ Some Disassembly ____ Much Disassembly ____

Minor Damage Overpressure ______ Major Damage Overpressure ______

Susceptibility to Missiles: 1/2-3 psi_____ 3-7 psi _____ >7 psi _____
(L - Light, M - Moderate, S - Severe)

Critical Electronic Components: Y or N _____

Utilities Required:
Electricity, peak kW _____ Natural Gas, peak Btu/hr _______
Water, peak gpm ________ Compressed air, peak cfm _______
Other ____

Numerical Relationship to Other Essential Equipment: Ratio ________
Related Equipment ____

Normal Annual Cost of Replacement Parts ($/yr) _____________
Delivery time, wks ______

Est. Cost of Vulnerable Key Non-site Repairable Parts ($) ______ (ID in comments)

Equipment Required for Loading on a Truck: jacks ____ crane ____ forklift ____
Delivery time, weeks _____

Ancillary Equipment Description: ___________________________________

Est. Time to Repair, wks	0-2 psi	2-6 psi	6-15 psi	15 + psi
	_______	_______	________	________

Comments: ____

____

Figure I-5

BUILDING DATA SHEET

Date ________________

Analyst ______________

Section ______________

Page ____ to ____

Facility: ______________________________________

Attachments:

Area Map ______________________________

Site Plan ______________________________

Building(s) Layout ____________________

Process Flow Chart(s) ________________

Building Inventory

Area Name			
Activity/Function			
Floor Area (Include Below Grade)			
Below Grade Area			
Roof Area			
No. of Floors Above/Below Grade			
Structural Type			
Wall Type			
Percent Window Area			
Roofing Material			
Product Activity			
SIC# _____/Percent _____			
SIC# _____/Percent _____			
SIC# _____/Percent _____			
Vulnerable to Collapse, psi			

Comments: ____

____

Figure I-6

CRITICAL INPUT MATERIALS

Date ________________

Analyst _____________

Section _____________

Page ____ to ____

Facility: ____

Material Name: __________________________ Originating SIC # _______

Shipping Form: Solid ____ Liquid ____ Gas ____

Bulk _____ Pallet ____ Container ____ Other _____

Shipping Unit: Weight _______ Size ____________________

Means of Delivery: Rail ____ Truck ____ Pipeline ____ Ship ____

Annual Use (Units): _________ Average Delivery Time (weeks) _____

Place of Storage: __________________

Equipment Required for Relocation: ______________________________

Susceptibility to Overpressure Damage: ___________________________

Susceptibility to Damage From Weather: ___________________________

Percent of Supplier (SIC) Capacity Located in 3-7 psi _____ 7+ psi _____

Can Other Materials/Suppliers be Substituted? (Y or N) ___________

Substitute Materials: ____

Comments ____

____

Figure I-7

EXPEDIENT PROTECTION DATA

Date ______________

Analyst ____________

Section ____________

Page ____ to ____

Facility: ____

Expedient Protection Equipment (On-Site or Employee Owned)

Shovels	_________	Front-end Loaders	_________
Picks	_________	Bulldozers	_________
Wheelborrows	_________	Forklifts	_________
Hammers	_________	Dump Trucks	_________
Nails	_________	Other	_________

Transportation Equipment (Captive)

	Quantity	Total Capacity
Pick-up Trucks	_______	____________
Panel Trucks	_______	____________
Vans	_______	____________
Tractor-trailers	_______	____________
Other	_______	____________

Sources of Dirt/Burial

Site Area: _____________________________

Parking Lot Area ________________________

Unpaved Area ___________________________

Distance to Source of Dirt ______________

Comments ____

____

____

Figure I-8

FACILITY UTILITY DATA

Date ______________

Analyst ______________

Section ______________

Page ____ to ____

Electrical Service

Incoming Electric Service: _____volts _____phase
Peak Electric Demand: kW _______ Annual Use, kWh _____
Capacity of Outdoor Transformers _______kVA Quantity __________
No. of Major Transformers Indoors: ______ Typical Size ____kVA
No. of Major Transformers Outdoors: ______ Typical Size ____kVA
Emergency Electric Generator Capacity: ________kW
Number of Key Circuit Breakers: ________Typical Sizes _____, _____

Central Process Heat Source
Type of System ____________________ Capacity (Btu/hr) _______________
Fuel Type _____________ Fuel Storage Capacity _____/days at capacity ____
Annual Fuel Use ________________
Fuel Storage Description ________________________________
Can alternate fuels presently be used: (Y or No) ________
Alternative Fuel Type: ____________________
Can the system be converted to use other fuels? ____________

Water Service
Process Water Requirements _______________gal/day at capacity
Source of Water ____
Fire Protection Sprinkler System? (Y or N) _______
Will water supply system operate during utility blackout? (Y or N) _______

Waste Water
Waste-Water Effluent (1000 gal/day) _______________
On-site Waste-Water Treatment Facility (Y or N) __________
Use Municipal Waste-Water Treatment Facility ____________
If municipal collection system were not working what would happen to waste-water?

____

Emergency electric generators for waste-water pumps? _____Y _____N

Comments ____

____

Figure I-9.

determine priorities for equipment protection. In other words this particular format does not seem to fit any of the criteria believed desirable for the format to be developed under this program.

The second candidate format is one developed by the Center for Planning and Research in Ref. 4 and is reproduced in Figure I-10. It is a very simple format, collects some basic data, but would be improved if a remarks column were included and the criteria for establishing the priority were available on the form.

The third candidate format is a refinement of one that was developed by SSI in 1979 for an earlier version of the Industrial Protection Guide, Ref 5. The format is shown in Figures I-11B-D. This format was tested previously (by industries) and has undergone several revisions during this program to reflect: the application to hazards other than nuclear war, industry experience, and the revised procedures for vulnerability assessment described in Part II. The revised format consists of three forms. The first is similar to the earlier format and is an equipment inventory procedure. The major revision is that the procedure requires, at the beginning, an assessment of an essential and replacement/repair rating of a piece of candidate equipment. By this early rating process, nonessential items are immediately eliminated and only essential items are included in the list for further analysis. These ratings are discussed below.

DISCUSSION OF FORMAT

In Figure I-11A a method for determining essential and replacement/repair ratings is presented. Each of these is discussed in more detail below:

Essential Ratings

"1 **Absolutely Essential** - Equipment required to operate either during the disaster period for emergency response, or after to ensure survival supplies for the population. Also includes one-of-a-kind items of equipment for which there is no substitute".

Equipment required to operate during a disaster might include: emergency communications equipment, medical and fire response vehicles, emergency power generators, and in the case of nuclear threat certain types of military support

PROTECTION PLANNING FORM

LOCATION:

____ SHEET NO.________ OF ________

(1)	(2)	(3)			(4)	(5)		(6)
ITEM NO.	ITEM	DIMENSIONS			NOT MOVABLE*	MOVABLE		PRIORITY
		L	W	H		CUBE	WT.	

* An item is not movable if it cannot be unbolted or disassembled in a period of 4 hours or less.

Fig. I-[illegible]. Protection Planning Form.

"E" Rating	Description
1	**Absolutely Essential** —— Equipment required to operate either during the disaster period for emergency response or after to ensure survival supplies for the population. Also includes one-of-a-kind items of equipment for which there is no substitue.
2	**Essential to the Process** —— Equipment that is key to some step in the production process and that would stop all regular production immediately if it were eliminated, but would not make it impossible to jury rig an alternative process with lower output. (One of a kind in-plant for current production level, but do-able via alternative process.)
3	**Essential for Normal Operations** —— Equipment that is required principally for normal operation of the plant, but for which there are several of a kind in-plant with production rate affected by numbers available.
4	**Non-Essential** —— Backup equipment used only for occasional peak demand periods or old outdated equipment.

"RR" Rating	Description
1	**Impossible** —— Refers to those items not repairable without new parts from outside, and outside help.
2	**Difficult** —— Includes those items that would be better sent outside for repair or replacement work, but might be replaced or repaired with some difficulty by in-plant personnel using materials and equipment on hand.
3	**Possible** —— Includes those items that could be repaired by inhouse personnel without too much difficulty using materials and equipment on hand.
4	**Easy** —— Refers to items for which many spares or substitute parts are commonly available both onsite and off and which can be repaired with resources on hand, or by simply jury rigging common materials.

Figure I-11A. Essential and Replacement Repair Ratings.

ESSENTIAL EQUIPMENT INVENTORY WORKSHEET (E+RR = 5 OR LESS)

NUMBER	E+RR	EQUIPMENT NAME & DESCRIPTION	QTY	WEIGHT (W) in lbs	HEIGHT (H) in ft	LENGTH* (L) in ft	DEPTH (D) in ft	REMARK

*Use Longest Horizontal Dimension

Figure I-11B. Essential Equipment Inventory Worksheet.

ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET

NUMBER	EXPOSED AREA IN SQ FT	WEIGHT/UNIT AREA IN LBS/SQ FT (W/A)	DENSITY FACTOR (F) = 0.002W/DHL	SURVIVABILITY SEE TABLE*

*Where W/A falls between listed values, use S for the smaller listing

VULNERABILITY/SURVIVABILITY TABLE

W/A	S
30	1
60	2
110	3
160	4
220	5
280	6
360	7
440	8
530	9
630	10
760	11
900	12
1100	13
1300	14
1500	15

Figure I-11C. Essential Equipment Vulnerability Worksheet.

COUNTERMEASURES/RESOURCES WORKSHEET

NUMBER	S	COUNTERMEASURE	LABOR REQUIREMENT TYPE	LABOR REQUIREMENT HOURS	MATERIAL REQUIREMENT TYPE	MATERIAL REQUIREMENT QUANTITY	EQUIPMENT REQUIREMENT TYPE	EQUIPMENT REQUIREMENT QUANTITY	TIME HOURS

Figure I-11D. Countermeasures/Resources Worksheet.

equipment. The one-of-a-kind types of equipment are a little more difficult to identify. Examples of this category are: giant skin mills used to machine aircraft wing sections such as the ones at the Boeing Aircraft Auburn facility, which are 20 ft in width and with machining beds 130 ft long (described in Ref. 6 and shown in Figure I-12); an automated production line for the production of engines such as the one shown in Figure I-13, and similar equipment that qualifies as the only one in the country or in the area and for which there is no alternative process. One must be careful here in that, for many one-of-a-kind items, there may be somewhere another way (earlier methods and equipment) of producing the product, albeit perhaps much more costly, less efficient, and at a lower production rate. This is discussed in more detail in the hardening and substitution discussion in Part II. For the essential equipment survey in individual facilities, however, the following criteria should be used: If it is the only one of its kind in the facility, is essential to the process, and if you do not know where to obtain another or how to jury rig one quickly, it should be included in the Absolutely Essential category.

> "2 **Essential to the Process** - Equipment that is key to some step in the production process which would stop all regular production immediately if it were eliminated, but would not make it impossible to jury rig an alternate process with lower output. (One of a kind in-plant for current production levels, but do-able via alternate process.)"

An example of this type of equipment might be a boiler in a food processing plant that could be replaced, with some effort and loss of production rate, with a portable steam supply. An example of this occurred at a local electronics plant when an accident destroyed the in-plant boiler and an old locomotive was brought in to supply steam while it was being repaired. Other examples are the automatic washing and cleaning equipment used in many production processes, which could be replaced with less efficient hand operations.

> "3 **Essential for Normal Operations** - Equipment that is required principally for normal operation of the plant, but for which there are several of a kind in-plant with production rate affected by numbers available."

Examples of this type of equipment would be a production line that consisted of a number of identical machines, e.g., milling machines or drill presses, or where there are several of the same type of equipment at various locations in the plant.

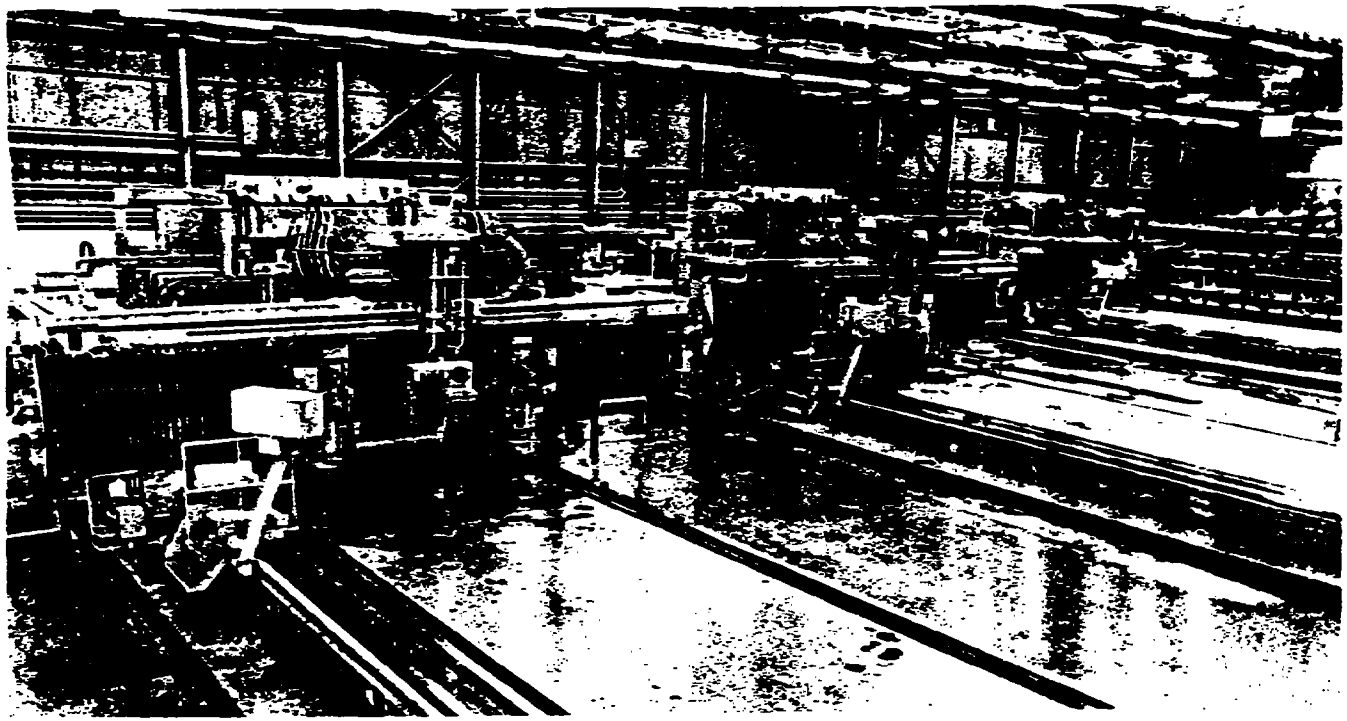


Fig. I-12. Skin Mills in Boeing Facility.

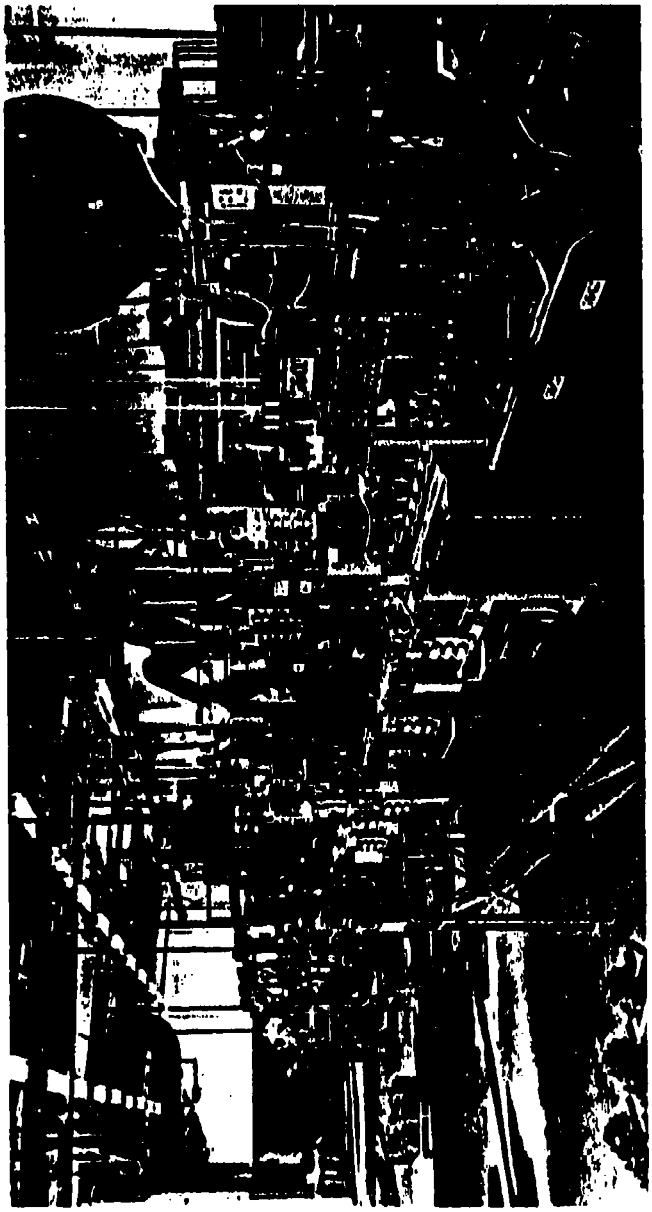


Fig. I-13. Automated Production Line.

"4 **Non-Essential** - Backup equipment used only for occasional peak demand periods or old outdated equipment."

On the surface this is an obvious category, but as will be noted later in the protection and hardening section it may be necessary to re-evaluate at some of these items of equipment. Equipment in this category is older than the equipment currently in the process lines, and usually it contains less sophisticated controls and is often more ruggedly constructed. Upon analysis, in some cases, it may be more desirable to protect some items of this equipment because they will be easier to protect.

Repair/Replacement Ratings

"1 **Impossible** - refers to those items not repairable without new parts from outside and outside help."

"2 **Difficult** - Includes those items that would be better sent outside for repair or replacement work, but might be replaced or repaired with some difficulty by in-plant personnel using materials and equipment on hand."

"3 **Possible** - Includes those items that could be repaired by in-house personnel without too much difficulty using materials and equipment on hand."

"4 **Easy** - Refers to items for which many spares or substitute parts are commonly available both onsite and off and which can be repaired with resources on hand, or by simple jury rigging common materials."

(Note that "resources on hand" may be vastly different in the abnormal environment during and following a disaster from those in the everyday normal evironment.)

The remaining items on the three forms are discussed in detail in Part II of the report, and examples of their use appear in Part III. For the most part, an item with a rating of 2 to 5 warrants consideration as essential, while some 5's and all items rated 6 or over should be considered non-essential for planning purposes.

PART II

SUMMARY OF TECHNICAL EFFORT

PART II

Section 1
INTRODUCTION

There were three main objectives to the work presented in this part of the report:

> to develop methods for predicting the vulnerability of industrial equipment to the blast waves from nuclear weapons;
>
> to determine the degree of protection provided by various means of reducing the vulnerability (countermeasures);
>
> to provide simplified procedures to enable the personnel responsible for an industrial plant to develop hardening plans for their installation using the above information.

Part II of the report is divided into sections; in Section 2, the various mechanisms that can cause damage to industrial equipment under blast loading are examined and compared to determine which mechanisms are of most interest. It is evident from these comparisons that the vast majority of damage is caused by one type of impact process or another, which leads, of course, to the conclusion that there is no unique vulnerability for an item of industrial equipment, but that the vulnerability will depend at least to some extent on its surroundings (environment). Procedures are then developed for predicting the basic vulnerability of an item of equipment; i.e., the vulnerability in its normal or as-is condition in an industrial building.

Section 3 describes the various countermeasures that can be implemented to decrease the vulnerability of the equipment and procedures are given for determining how much protection each of these countermeasures provides.

In Section 4 the procedures suggested for calculating the basic vulnerabilities and for determining the protection factors for the various countermeasures are evaluated by comparing their predictions with existing data from nuclear and large

scale HE tests. The test data are somewhat limited and do not cover all aspects of the prediction procedures; wherever comparisons are made, however, the predictions are consistent with the test data. In effect, the first four sections of Part II discuss the technical base for development of the guidance needed for industrial survival.

A test program, presented in Section 5, is designed to fill in the gaps in our technical knowledge of the response of industrial equipment to blast and in the degree of protection provided by certain countermeasures. Applications gaps are discussed in Part III.

The various calculations and reference material used in deriving the prediction methods are given in Appendix A.

Part V is a manual for use by plant personnel; it gives the simplified procedures for evaluating equipment vulnerability and developing hardening plans.

Section 2
VULNERABILITY OF INDUSTRIAL EQUIPMENT TO NUCLEAR EXPLOSIONS

BLAST EFFECTS

There are a variety of ways by which industrial equipment can be damaged by a blast wave. These are listed in Table II-1.

Table II-1
DAMAGE MECHANISMS FOR INDUSTRIAL EQUIPMENT

1. Overturning and impact on the ground surface

2. Overturning followed by tumbling resulting in multiple impacts on the ground surface

3. Translation followed by impact against other surfaces such as other equipment and building walls and columns

4. Impact by loose missiles picked up by the dynamic pressure in the blast wave

5. Impact by missiles created by the breakup of frangible walls of the building housing the equipment

6. Impact by roof elements created when the building housing the equipment collapses

7. Direct air blast causing crushing, deforming, and/or rupturing

It may be seen that, except for the last mechanism, the damage is caused by an interaction between the equipment and its environment. For the overturning mechanisms, for example, the important environmental factor is the nature of the

ground surface, while for translation and impact it is the type of building that houses the equipment and the nature of the adjacent equipment. Table II-2 gives the environmental factors of concern for each of the damage mechanisms.

Table II-2
LOCAL ENVIRONMENT FACTORS IMPORTANT
TO EQUIPMENT DAMAGE MECHANISMS

Damage Mechanisms	Environmental Factors
1. Overturning/impact	Nature of ground surface
2. Overturning/tumbling/impact	Nature of ground surface
3. Translation/impact	Type of adjacent equipment Type of building
4. Impact/loose missiles	Degree of protective housekeeping
5. Impact/wall fragments	Type of wall
6. Impact/roof elements	Type of roof
7. Direct air blast/crushing/deforming/rupturing	None

From Table II-2 it is evident that the determination of the damage to industrial equipment is a very large job since it involves seven different damage mechanisms combined with five environmental factors plus a wide variety of industrial equipment. It seems evident that some types of generalizations will be necessary to reduce the problem to manageable proportions.

As a start on this, each of the damage mechanisms is discussed in the following subsections and compared with the other mechanisms to try to determine their relative importance. This also should aid in determining the equipment characteristics that affect the damage process and thus help in the equipment categorizing process. It should be noted that in general there is insufficient

information available to actually compare damage caused by one mechanism with that from another; however, with the exception of direct blast all the others involve an impact process, so that the impact velocity and the nature of the impacting surfaces can be used as relative indicators of damage.

It also should be noted that the primary interest is in what will be called severe damage, i.e., the degree of damage such that the equipment cannot be used post-attack without a major repair job (which usually cannot be done in-house) and/or replacing major parts of the equipment (which are not commonly stocked in-house and have long lead times even under pre-attack conditions). Although it is not clear at this point, there may be a secondary interest in determining the degree of damage that will make the equipment inoperable without making minor in-house repairs and or replacements of parts. One possible reason for wanting this information is to determine at what pressure level significant repair effort and stocking of spare parts will be needed in-house to resume production. This degree of damage will be referred to as minor damage. Note that the threshold pressure for minor damage can be increased significantly by applying the relatively simple countermeasure designated as protective housekeeping (see Ref 7). Protective housekeeping among other actions includes removing lightweight and fragile exterior appendages to the equipment such as handwheels, control levers and mechanisms, exposed electrical components, gauges, etc. Protective housekeeping not only raises the threshold for minor damage but also reduces the need for spare part stocking and the repair effort required to put the equipment back in working order.

The sources of the various equations, graphs, and charts used in the following discussion are given in Appendix A.

1. Overturning/Impact

It is suspected that in many, if not all, cases this damage mechanism will set the threshold for the start of damage, i.e., if the equipment does not achieve sufficient velocity under blast loading to have a chance to overturn then it will not be damaged. For equipment in the open away from any structure or other equipment the only other possible mechanism is number 7, direct blast, and as will be discussed more later it is believed that, except for several rather limited classes of equipment, this damage mechanism requires very much higher pressures than overturning to be important.

It can be shown that at the overturning threshold the equipment will slide a distance of less than the depth (D) of the equipment. (The depth is the horizontal dimension of the equipment in a direction normal to the blast wave front.) The specific sliding distance as a fraction of its depth depends on the the ratio of the depth of the equipment to its height (H). Typical values are given below (from Appendix A, Section A-2).

D/H	Sliding Distance
0.25	0.12D
1.0	0.41D
4.0	0.78D

It should be noted that with such a small amount of sliding it is unlikely that damage translation/impact would occur even if the equipment were in its normal location in a structure except possibly for equipment having a large D and a large D/H ratio.

The velocity, V_o, that will permit overturning is shown in Figure II-1 (from Appendix A, Sections A-3, A-4, and A-5). It can be seen that it depends on the depth of the equipment and the D/H ratio. For symmetrical equipment, D/H = 1, the velocities range from about 5 ft/sec for a D of 2 to 10 ft/sec for a D of 8. Note that for D/H values between 1/2 and 2 the velocity values are within about 25% of the values for a D/H = 1.

2. Overturning/Tumbling/Impact

This damage mechanism obviously requires a higher overpressure level and would be expected to cause greater damage to the equipment than simple overturning. However, because the impacts result from tumbling along the ground surface it would be expected that the damage would be less than for translation/impact for the same initial velocity because the latter assumes impact against a vertical surface. If tumbling is terminated by impact against a vertical surface it would be considered under translation/impact. Note also that in the tumbling case the surface impacted will likely be concrete for equipment inside a building and concrete, black top, or dirt for equipment outdoors. The impacted surfaces for translation/impact range from massive metal (heavy equipment) to concrete columns or walls to lightweight siding for the structure. Since it appears that translation/impact will cause serious damage at lower incident overpressures

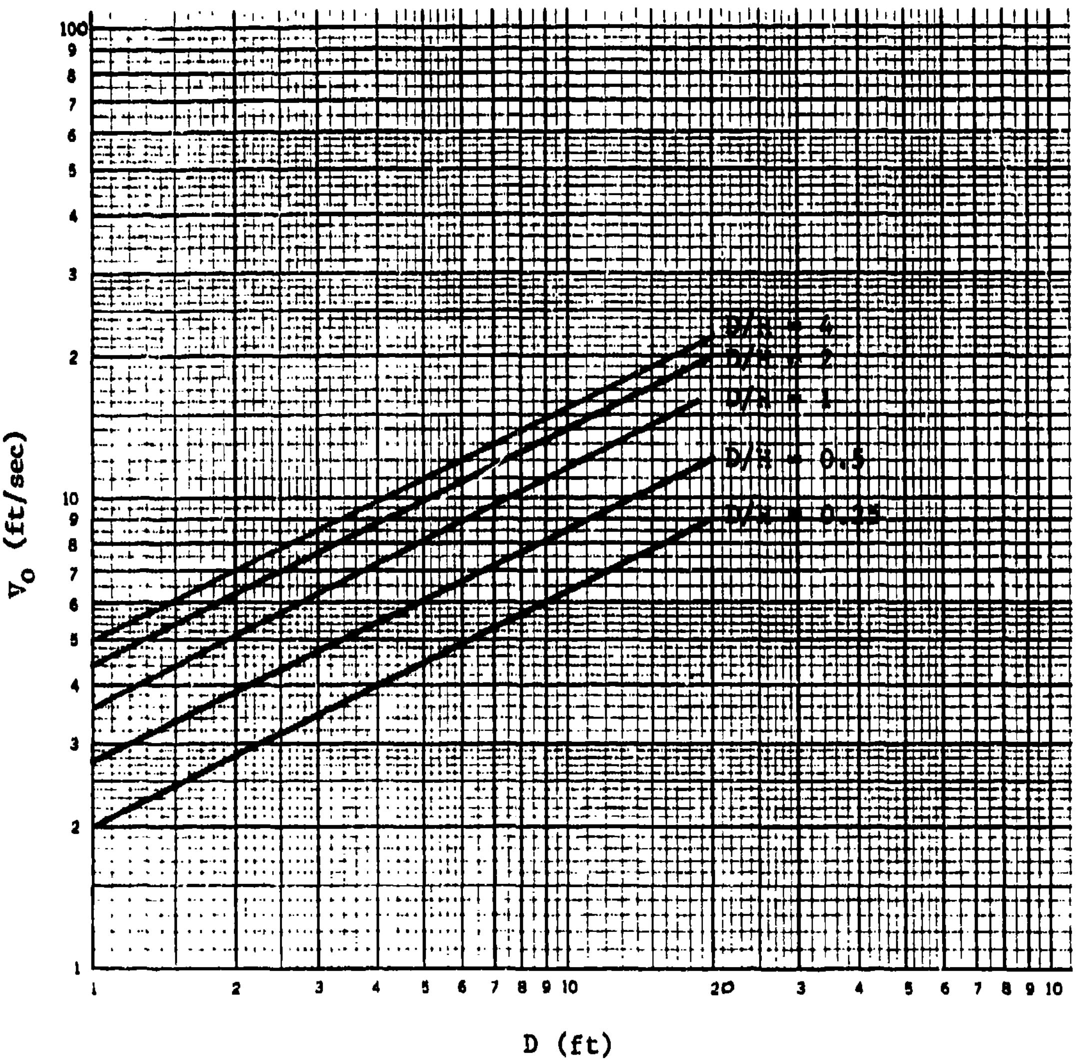


Fig. II-1. Overturning Velocity vs D for Various D/H Ratios.

than overturning/tumbling impact, further consideration of the latter will be deferred until later.

3. Translation/Impact

This damage mechanism is expected to be one of the most important in regard to causing severe damage to equipment. Figure II-2 is a plot of the velocity, v, achieved by an object under blast loading as a function of the dynamic pressure impulse, I_q, for various values of the product DF where F is the ratio of the density of the object to that of steel (from Appendix A, Section A-1). Shown in Appendix A, Section A-6) are the overpressure levels necessary to give the various I_q values for various weapon yields. As discussed in Appendix A, this graph assumes the equipment is impulsively loaded and the blast wave is unmodified by the structure.

To get some idea of what the various velocity values mean there is shown on the right side of Figure II-2 a scale labeled drop height. This means that if the equipment were dropped from the given height it would impact the ground surface with the velocity given by the left scale. It can be seen that dropping the equipment from a 1-ft height gives an 8 ft/sec impact velocity, and from 4 ft, a 16 ft/sec velocity. Typical values are given below:

Drop Height	Impact Velocity
1	8
2	11
4	16
8	23
16	32
32	45

It seems logical that dropping most items of equipment a foot or so onto a massive concrete surface would be unlikely to cause serious damage, which means that the threshold velocity for causing serious damage from this mechanism is approximately 10 ft/sec. At the other limit it would seem reasonable to expect that the large majority of industrial equipment would become seriously damaged if dropped from say 15 ft onto a massive concrete slab. This gives an upper limit to threshold velocity for serious damage on the order of 30 ft/sec. This does not mean that serious damage cannot occur at lower impact velocities but that it is almost certain to occur at this limit.

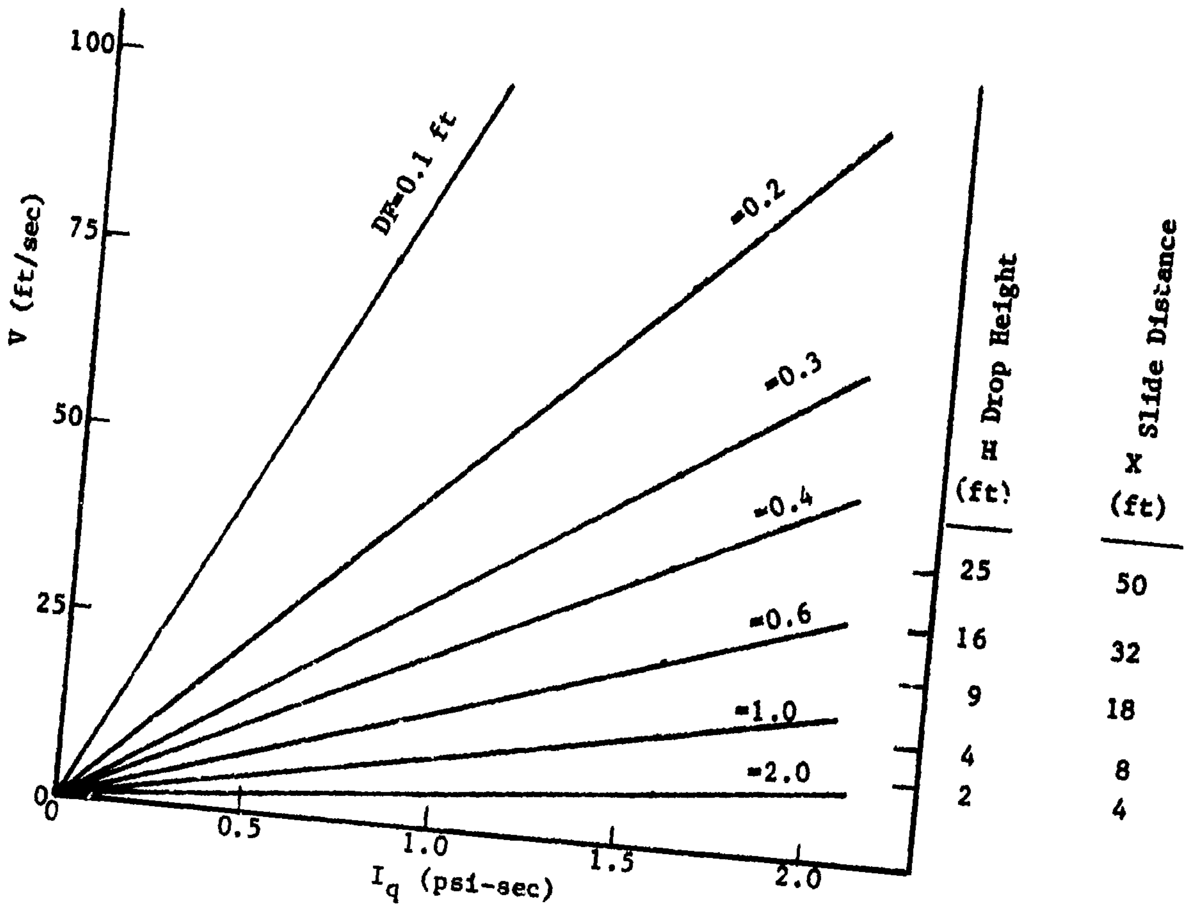


Fig. II-2. Velocity Achieved by Equipment Under Blast Loading vs Dynamic Pressure Impulse (I_q).

Another way to help visualize the implications of what the velocity means is through the likely distance the equipment will slide. This is also given on the right side of Figure II-2 (from Appendix A, Section A-3, A-4, and A-5). It can be seen that at 10 ft/sec the equipment is expected to slide less than 4 ft. This means that the equipment is not too likely to impact another piece of equipment or part of the building. Even if it does it will not be going at its initial velocity of 10 ft/sec. This reinforces the use of the 10 ft/sec as a lower limit for the sliding/impact case.

Now referring back to the overturning case (see Figure II-1), it can be seen that 10 ft/sec is also about right for the start of overturning for moderate to large size equipment. For D/H values from 0.5 to 2.0 the overturning velocity is within 20% of 10 ft/sec for D values ranging from 5 to 12 ft. For the smaller equipment with D values less than 5 the overturning velocities are less than 10 ft/sec. For example, for a D/H of 1 and a D of 2 the overturning velocity is 5 ft/sec. Such small equipment, however, is not very likely to be significantly damaged on overturning so that to a first approximation the 10 ft/sec lower damage limit holds for overturning/impact and translation/impact.

There is one class of equipment for which overturning will occur at velocities significantly below 10 ft/sec and that is equipment whose height is several times its depth. Consider for example a piece of equipment such as a drill press, which may have a D of 2 to 3 ft and an H of 6 ft. Such a piece of equipment could overturn at velocities as low as about 3 to 4 ft/sec. Rather than lower the 10 ft/sec to account for this special class of equipment it is planned to treat it separately in the prediction procedure as will be discussed later. Another reason for not lowering the basic limit is that with the simple countermeasure of reorienting (i.e., turning the equipment on its side) this effect can be largely eliminated.

For 30 ft/sec the expected sliding distance is about 30 ft, which for a normal factory layout pretty well assures that the equipment will impact against another piece of equipment or part of the building while it still has a sizable portion of its initial velocity. Thus, the consideration of sliding distances also further reinforces the use of 30 ft/sec as an upper limit for the translation impact case for a normal factory layout.

It is not at all clear, however, that it is a good number for the pure tumbling/impact case (damage mechanism number 2). It is believed that this case,

i.e., equipment outdoors isolated from other equipment and buildings, is a rare case normally, and is of importance only when countermeasures are being implemented to protect the equipment. Consider, for example, a piece of equipment that tumbles along the ground surface making say 3 or 4 individual impacts. Very crudely it might be postulated that it loses about 25% to 30% of its velocity on each impact. This type of argument strongly suggests that 30 ft/sec is not a good upper limit for the pure tumbling/impact case.

The plausability arguments given suggest that the vast majority of industrial equipment will not be seriously damaged by overturning-impact and translation-impact if the equipment is accelerated to velocities of less than about 10 ft/sec and that the equipment will be severely damaged if accelerated to velocities of greater than about 30 ft/sec. This excludes the case of pure tumbling impact, which will be considered further later.

4. Impact/Loose Missiles

It is not believed that this damage mechanism will turn out to be of much importance compared to the other mechanisms and since it can be virtually eliminated by practicing protective housekeeping measures, a relatively simple task, further consideration of this mechanism will be deferred until later.

5. Impact/Wall Fragments

If the structure housing the equipment has relatively heavy frangible walls such as brick, concrete block, or clay tile, then these constitute potential sources of damaging missiles because such walls are inherently quite weak and will typically fail at overpressures as low as a few psi. The velocities achieved by the wall fragments as a function of overpressure are given in Figure II-3 (from Appendix A, Section A-7). It can be seen that they depend on the ratio of the weight of the wall to its cross-sectional area exposed to the blast (W/A). These particular curves are for a wall that is located head-on to the blast wave so the applied overpressure is the peak reflected value. Curves for an 8-in. brick wall (with a W/A of 80 lb/sq ft) and an 8-in. concrete block wall (with a W/A of 37) are included on the figure.

One way to visualize what the effects might be on a piece of equipment if it is impacted by such a fragmented wall is to consider what might happen if the equipment were accelerated and impacted a stationary wall. This is somewhat similar to the impact process discussed above. Earlier, however, it was visualized

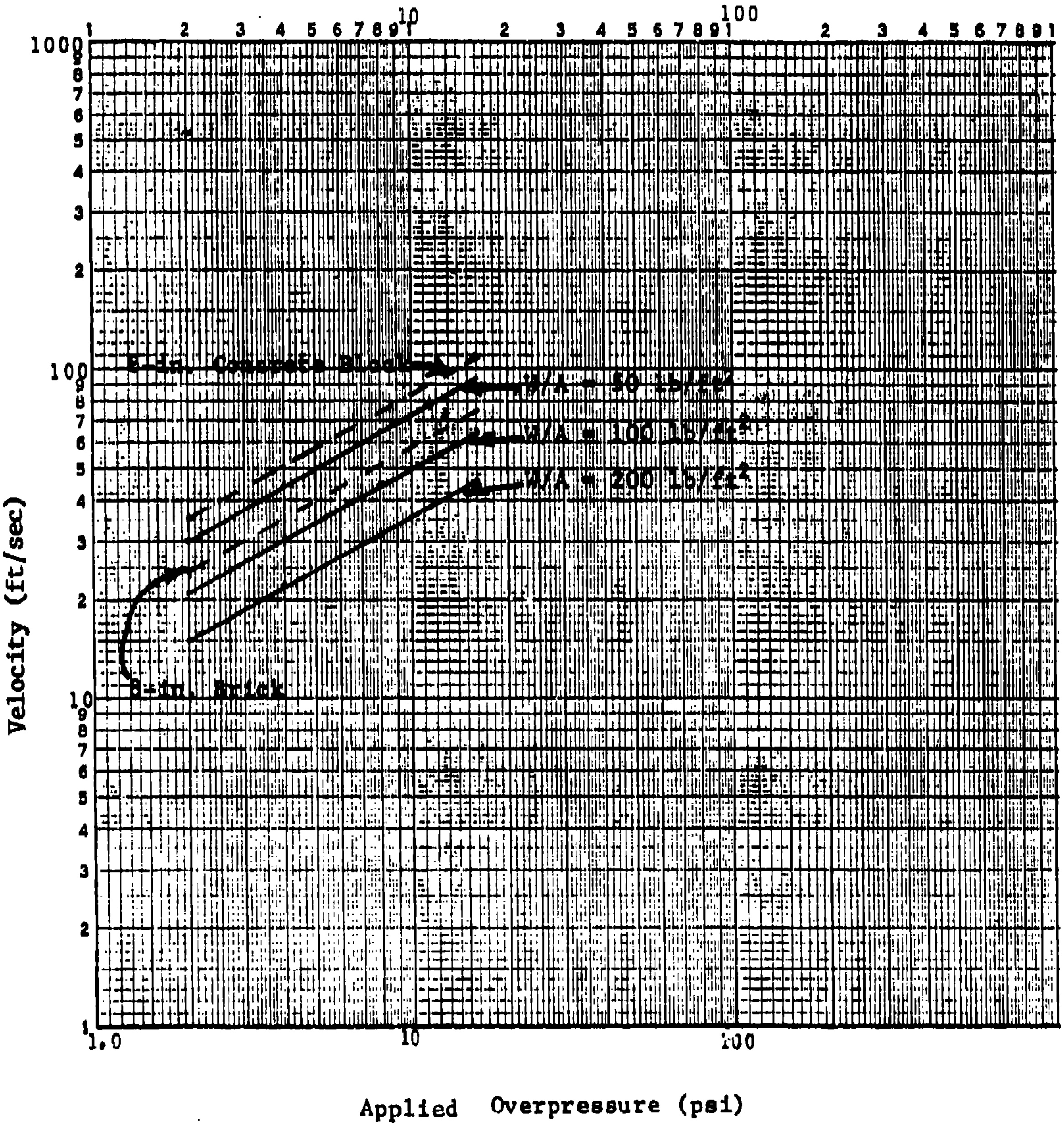


Fig. II-3. Velocity of Wall Fragments vs Overpressure for Various W/A Values.

that the impact would be against rather massive surfaces such as concrete floors or heavy equipment, while now this is not necessarily the case. For light equipment there probably is not much difference since the brick and concrete block walls, for example, may act as massive as a concrete floor. For heavy equipment, however, it is believed that there may be a big difference because of the likelihood of the equipment punching through the wall.

For the punching case, it has been proposed that the effective impact velocity of the equipment be taken as its velocity change (i.e., the velocity of the equipment after being impacted by the wall); this is readily calculated from simple mechanics (see Appendix A, Section A-8). The result has been applied to produce a plot (Figure II-4) of the ratio of the effective velocity (V_e) to the initial wall fragment velocity (V_w) as a function of parameters of the equipment, for the case of impact by an 8-in. brick wall. In the figure, the velocity ratio is shown in terms of the weight of the equipment and the ratio of the density of the equipment to the density of steel (F) for equipment having a cubical shape. Note that heavy equipment is assumed to have a total weight of about 5,000 lb or more and to have an F value of greater than about 0.1. For heavy equipment it can be seen that the effective impact velocity is less than 25% of the actual wall fragment velocity.

Medium sized equipment is considered to be from, say, 500 to 5000 lb in weight and with F values ranging from 0.1 to 0.2. For these conditions the effective impact velocity ranges from about 20% to 40% of the actual wall fragment velocity.

Light equipment is considered to weigh less than 500 lb and to have F values of less than 0.1. For these conditions the effective impact velocity is at least 40% and in most cases considerably higher. This confirms the earlier suggestion that for lightweight equipment an 8-in. brick wall is not too different from a massive concrete surface.

Using the data on wall fragment velocity versus incident overpressure in Figure II-3, the effective impact velocities are plotted vs incident overpressures in Figure II-5 for the three weight categories of equipment just discussed. Accordingly, for heavy equipment a reduction to 20% of the actual wall fragment velocity was used; for medium equipment, a reduction to 30%; and for light equipment, a reduction to 70%.

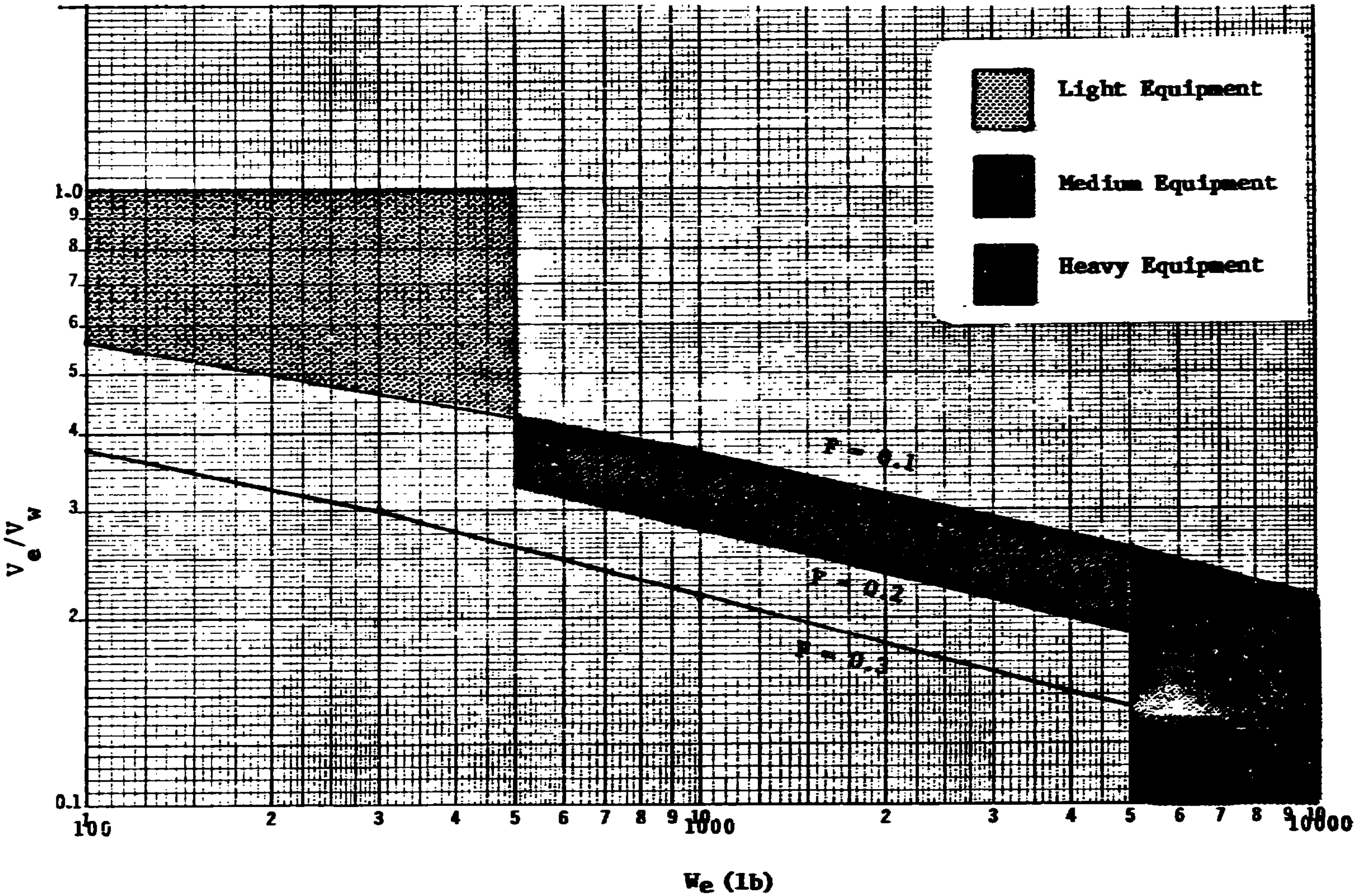


Fig. II-4. Ratio of Effective Impact Velocity to Wall Fragment Velocity as a Function of Equipment Weight (W_e) and F Value for an 8-Inch Brick Wall.

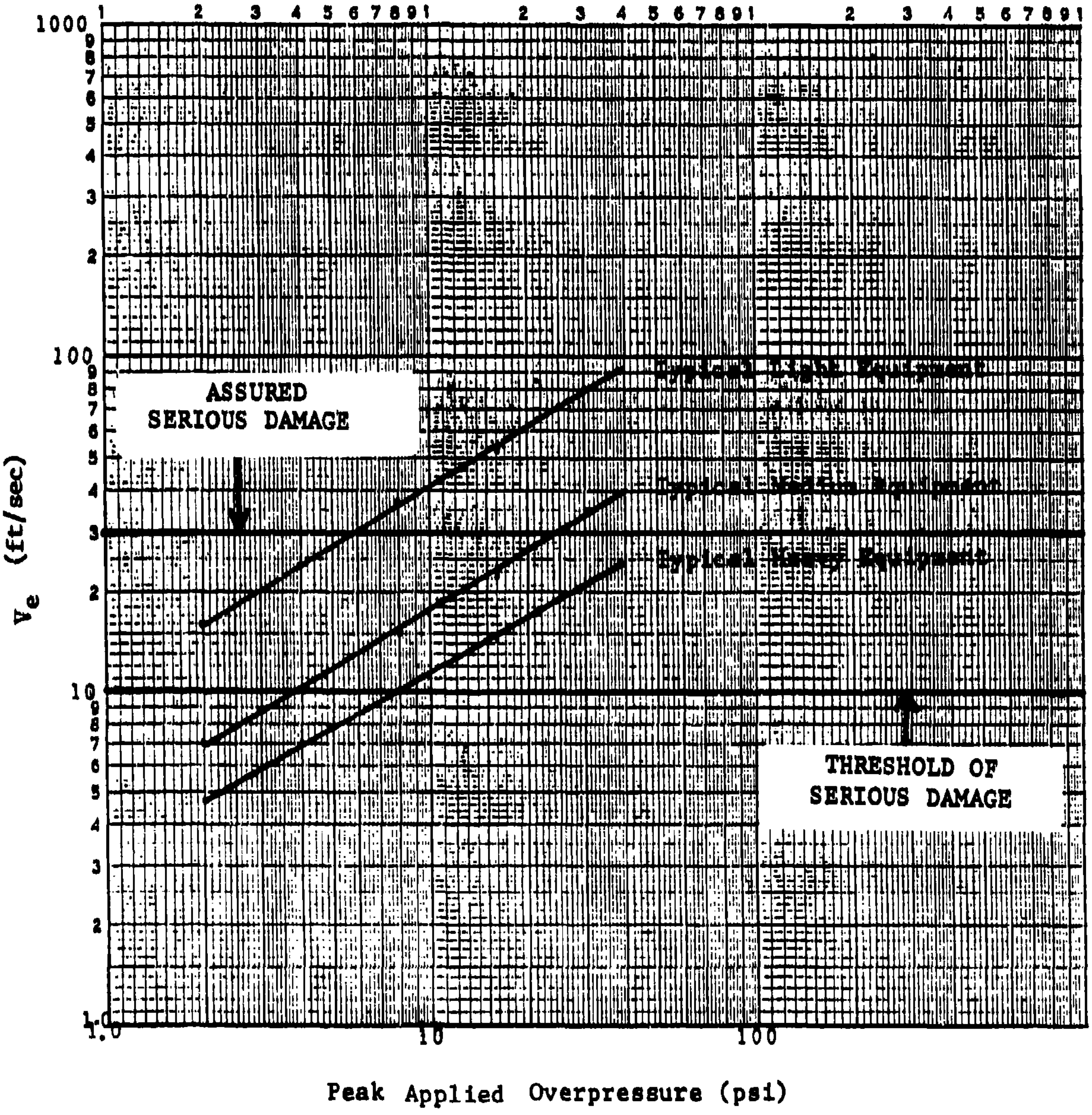


Fig. II-5. Effective Impact Velocity of Wall Fragments From an 8-Inch Brick Wall vs Overpressure for Various Equipment Classes.

In order to compare the relative importance of damage from translation/impact with that from wall fragment impact, calculations were made of the peak overpressures, P(T/I), necessary to give equipment velocities of 10 and 30 ft/sec by the translation/impact mechanism and the pressure, P(WF), necessary to give 8-in. thick brick fragments the same effective impact velocities. The 10 and 30 ft/sec velocities were used because they have been tentatively identified as the threshold for any impact damage and the level at which most equipment is almost sure to be severely damaged, respectively. The results are given in Figure II-6, which is a plot of the ratio of P(T/I) to P(WF) as a function of equipment weight and F value (ratio of density to that of steel). The calculations assumed a cubical shaped object.

From a consideration of Figure II-6 it can be seen that for almost the entire range of conditions considered the translation/impact damage mechanism is much more important than the wall fragment impact damage mechanism. Only for lightweight, low density equipment does the wall fragment damage mechanism predominate and then only at the threshold of damage (v = 10 ft/sec). If non-symmetrical equipment is considered, the wall fragment case increases somewhat in importance but not sufficiently to change the overall conclusion except possibly for extreme non-uniformities. This is illustrated in Figure II-7, which is a plot similar to Figure II-6 except that the weight per unit area exposed to the blast is only 1/4 that for a cube. From Figure II-7 it can be seen that a somewhat larger range of conditions leads to pressure ratios greater than one but again it is only near the threshold of damage and then only for lightweight low density equipment. It also should be noted that the 8-in. thick brick wall, which weighs 80 lb/sq ft, is just about the most massive wall that will be encountered (the practical upper limit is estimated at 100 lb/sq ft). Since the fragment hazard would be even less for lower density walls, it is concluded that in general the translation/impact damage mechanism is more important than the fragment impact damage mechanism.

6. Impact/Roof Collapse

Equipment damage by this mechanism is one of the most difficult to predict. To date a very common approach has been to assume that the equipment is severely damaged if the building housing the equipment collapses, and since it is further assumed that most buildings collapse at a few psi (2 psi is often mentioned) this leads to very low overpressures for severe damage--overpressures in general significantly lower than for the impact cases discussed earlier. Although this may be true for some cases it seems possible that it is an overly conservative assumption in general,

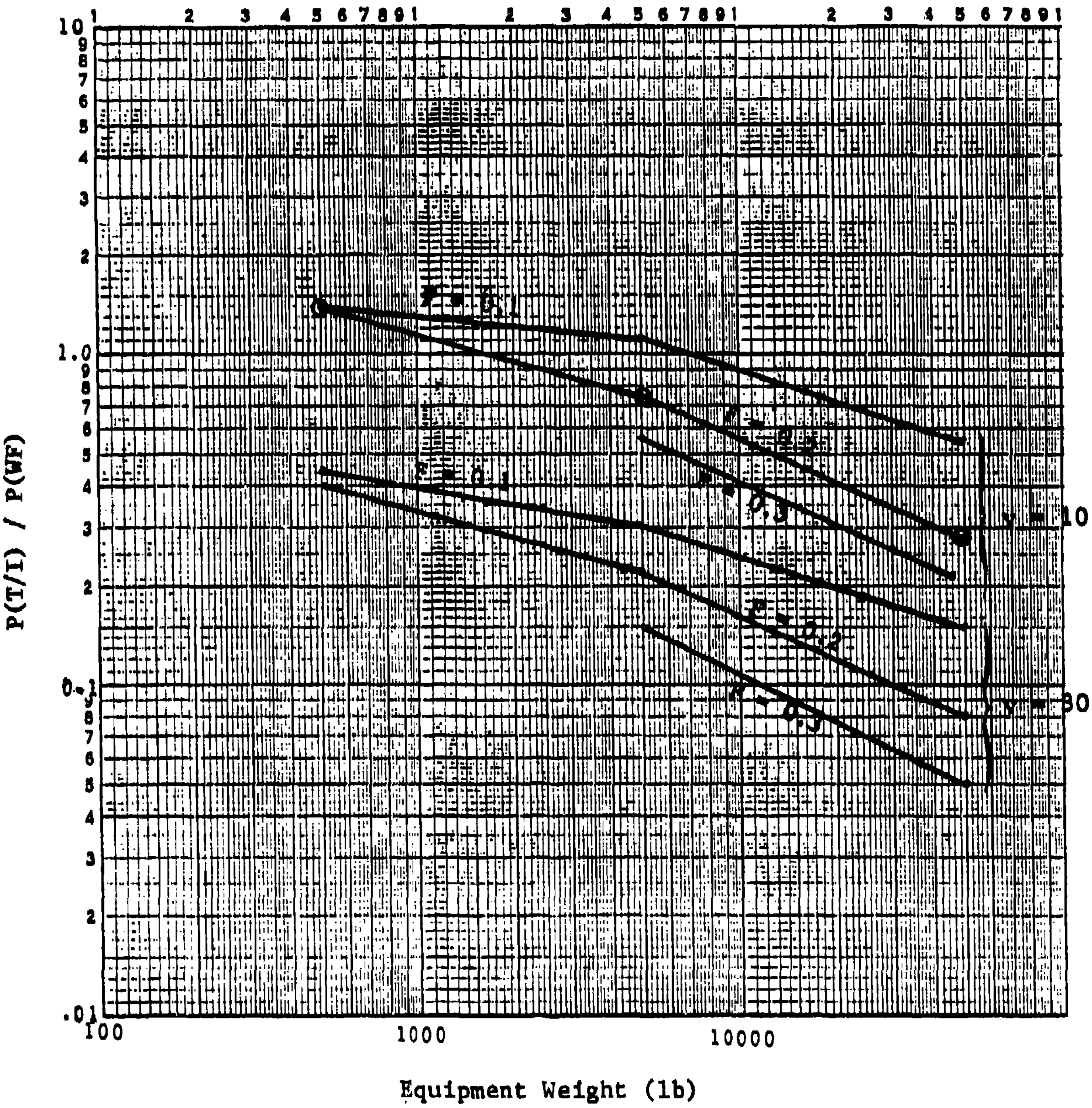


Fig. II-6. Ratio of P(T/I) to P(WF) for an 8-Inch Brick Wall vs Equipment Weight and F Value for v = 10 and 30 ft/sec.

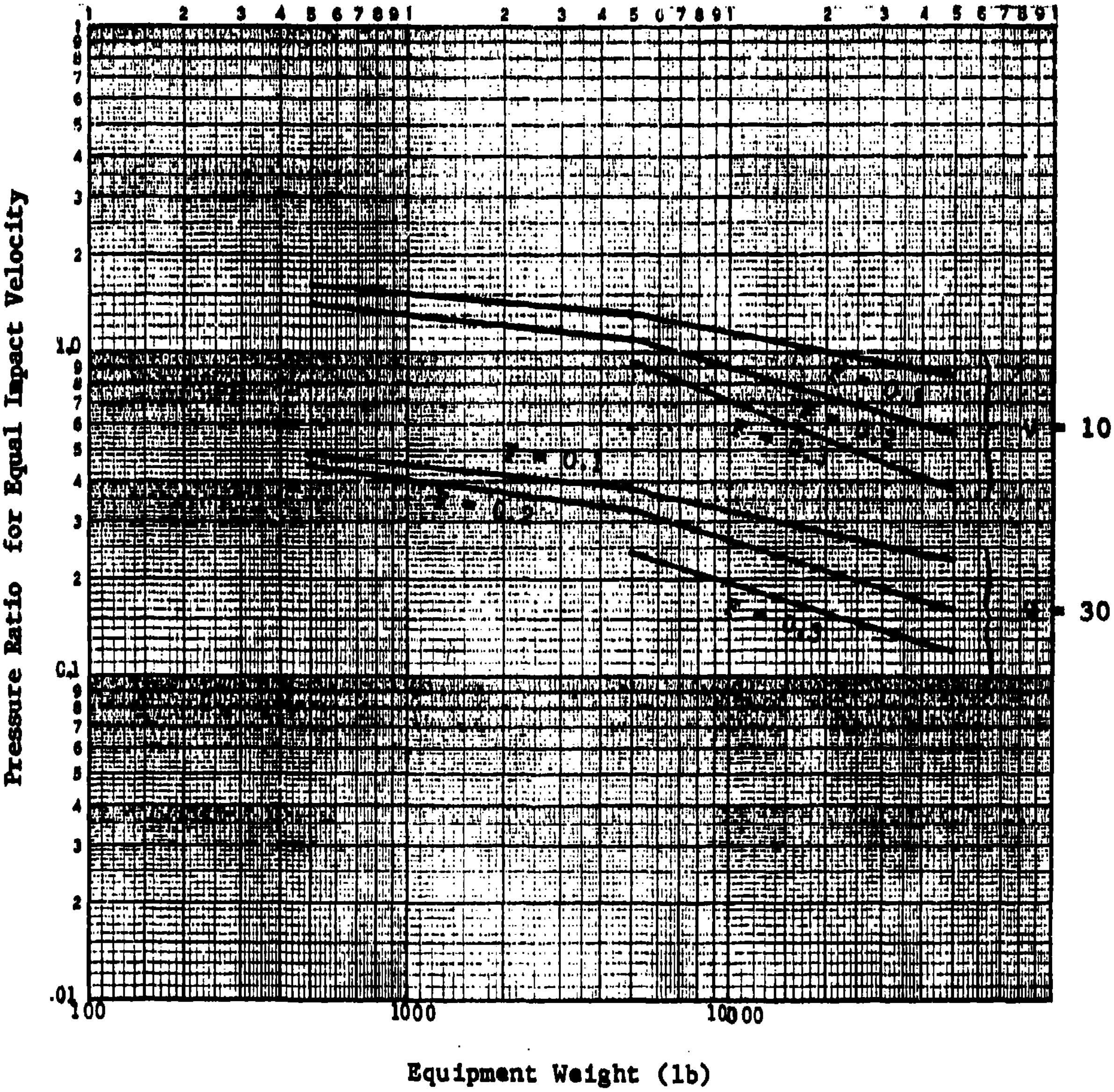


Fig. II-7. Ratio of P(T/I) to P(WF) vs Equipment Weight and F Value for v = 10 and 30 ft/sec. Weight per unit area is 1/4 that for Fig. II-6.

and for this reason it seems worthwhile to give it further consideration. The problem has three main aspects: what are the overpressure levels that cause structural collapse for the types of buildings of concern for industrial equipment; how does the structure collapse; and what actually happens when the roof impacts the equipment? The latter question will be considered first.

If the structure collapses its roof elements will impact on the equipment. If the walls of the building are rapidly blown away, as is likely to occur for most industrial buildings, the roof will impact the equipment with a velocity given by gravity. The gradual yielding of inelastic portions of the structural system, however, may reduce the impact velocity somewhat below that due to gravity alone. Taking the height of the roof of the building as ranging from 12 to 20 ft gives an average drop height of 16 ft, which leads to an impact velocity of 32 ft/sec. If the roof is extremely massive then, as noted earlier, this impact velocity is expected to cause severe damage to most industrial equipment. However, if the roof is not extremely massive but, for example, more like the walls considered above, then this velocity may not cause severe damage depending on the equipment characteristics. Table II-3 lists a variety of roof types for industrial buildings along with their typical weight per unit area. (See Appendix A, Section A-9 for more details.)

It can be seen from Table II-3 that for all but one of the roof types the weight per unit area is less than about 20 lb/sq ft. The one exception is the concrete roof, which had a weight/unit area of about 40 lb/sq ft. These amounts to 25% and 50% of the weight per unit area of the 8-in. brick wall discussed earlier. The effects of this lower weight/unit area are shown in Figure II-8, which is a plot similar to Figure II-4, except that it is for a weight/unit area of 20 lb/sq ft, or 25% of that used in Figure II-4. The important information that can be obtained from this figure is summarized in Table II-4 along with results from similar calculations for a 40 lb/sq ft roof and those obtained from Figure II-4 for an 80 lb/sq ft roof.

Table II-4 shows the effective impact velocity for the 20 lb/sq ft roof on light equipment ranges from 5 to 12 ft/sec. With 10 ft/sec as the threshold and 30 ft/sec as the assured upper limit for serious damage, it seems likely that most light equipment would not be severely damaged. For medium equipment the maximum velocity is 5 ft/sec and for heavy equipment 3 ft/sec. Thus, no severe damage would be expected for either of these cases.

Table II-3
TYPICAL ROOF SYSTEMS

Roof Type	Weight/Area (lb/sq ft)
Timber Roof Systems	
Sawn Lumber Joists	11
Glulam Timber Joists and Beams	13
Gabled Wood Roof Trusses	12
Manufactured Wood Joists	23
Open-Web Joist Roof Systems	
Open-Web Steel Joists	23
Open-Web Manufactured Wood/Steel Composite Joists	12
Concrete Roof Systems	
Precast Prestressed Concrete Hollow-Core Plank	41

Table II-4
EFFECTIVE ROOF IMPACT VELOCITY AS A FUNCTION OF ROOF TYPE

Equip Class	Equip Weight (lb)	Equip F Value	Roof Impact Velocity (ft/sec) Actual	Roof Impact Velocity (ft/sec) Effective
	Roofs Having a Dead Weight Loading of 20 lb/sq ft			
Light	< 500	0.05 - 0.1	32	5 - 12
Medium	500 - 5000	0.1 - 0.2	32	2 - 5
Heavy	> 5000	0.1 - 0.3	32	< 3
	Roofs Having a Dead Weight Loading of 40 lb/sq ft			
Light	< 500	0.05 - 0.1	32	9 - 16
Medium	500 - 5000	0.1 - 0.2	32	3 - 9
Heavy	> 5000	0.1 - 0.3	32	< 5
	Roofs Having a Dead Weight Loading of 80 lb/sq ft			
Light	< 500	0.1	32	13 - 32
Medium	500 - 5000	0.1 - 0.2	32	6 - 13
Heavy	> 5000	0.1 - 0.3	32	< 8

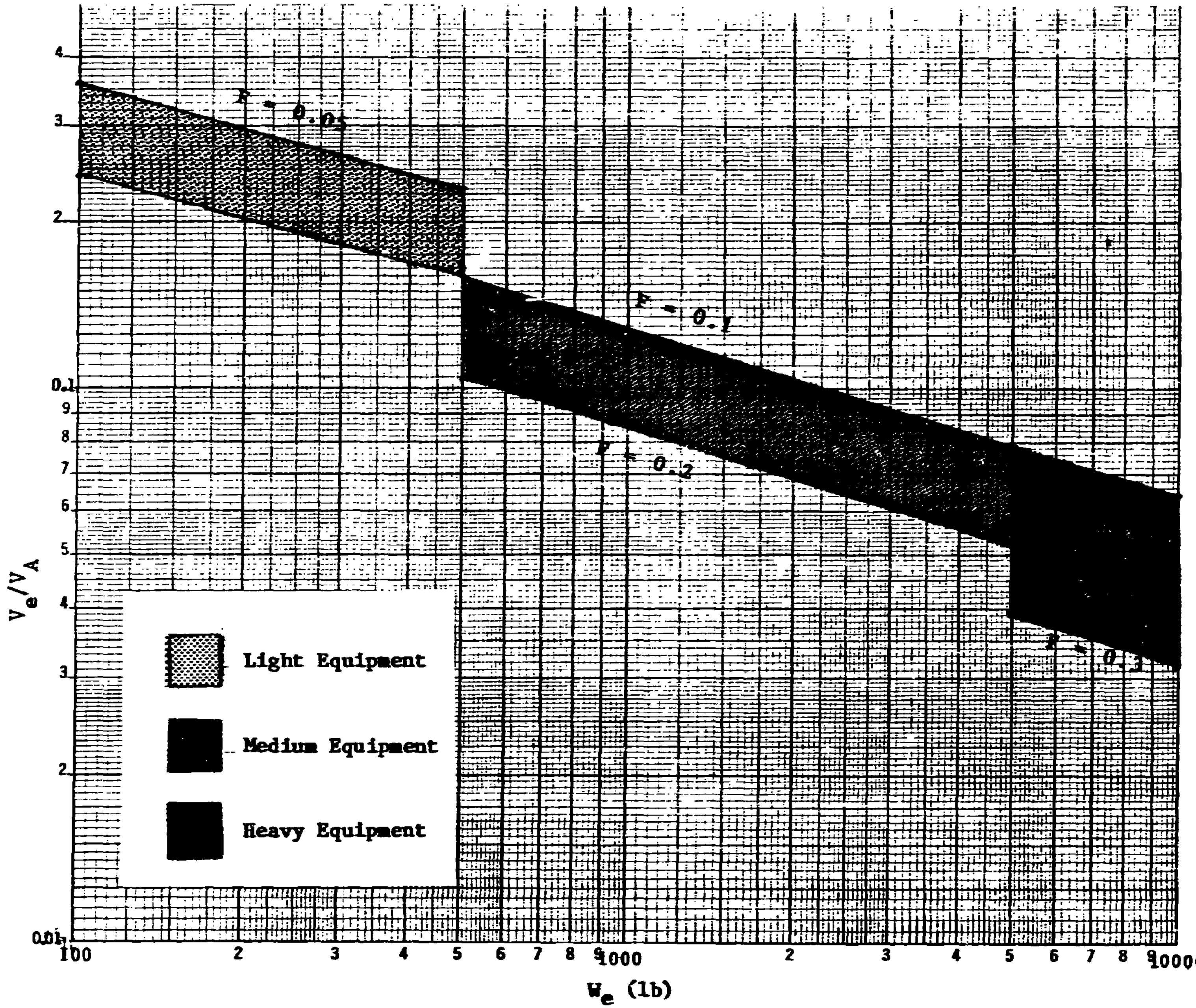


Fig. II-8. Ratio of Effective Impact Velocity to Roof Impact Velocity as a Function of Equipment Weight (W_e) and F Value for a Roof Having a Unit Dead Weight Loading of 20 lb/sq ft.

For the 40 lb/sq ft roof the majority of light equipment would be expected to be severely damaged, but very little of the medium or heavy equipment.

So far the roof has been treated just the same as the walls, i.e., being frangible in nature and having a uniform weight/area. In reality, however, there are non-uniformities (particularly for the lighter roofs) such as beams, joists, and trusses, which have a somewhat higher weight/unit area than the average and are not frangible so that they can transfer more load to the impacted equipment than just that portion of the member that contacts the equipment. Note that, if the increase in effective impacting weight/unit area due to these factors is no more than a factor of 4, the heavier portions of the 20 lb/sq ft roof act the same as the 80 lb/sq ft roof for which Table II-4 shows that almost all light equipment would be severely damaged since the velocity range is from 13 to 32 ft/sec, little of the medium equipment, and none of the heavy equipment.

Note that the factor of 4 mentioned above is in general expected to cover most but not all conditions. One of the conditions not covered, for example, is a long span, heavy glulam joist or beam. For this case the factor may run as high as 10.

The overall conclusion from the above analysis is that if the effective impact velocity concept is substantially correct, only lightweight equipment is expected to be seriously damaged by the collapse of most buildings and then only if it is hit by a major structural element. For roofs containing massive beams, even medium and heavy equipment can be seriouly damaged, but again only if they are hit by one of the beams; this would seem to be a moderately low probability event.

Note also that it is not uncommon to find heavy items of equipment mounted on the roof, which may constitute a serious hazard somewhat like the heavy beams. The probability of their impacting a given piece of equipment would seem to be quite low in this case, however.

Since it has been argued that collapse of the building is not a very serious damage mechanism except in special cases, there is less interest and priority in the other parts of the problem, i.e., what overpressure levels cause the structures to collapse and how do they collapse, so that no further consideration of these areas will be given.

7. Direct Air Blast/Crushing/Deforming/Rupturing

This damage mechanism is of concern only to selected types of equipment that can be divided into two broad classes:

1. Items of equipment that are really structures and are mounted to the ground surface (or other massive surface) in such a way that they cannot move as a single unit under the blast loading without causing serious damage to themselves. Equipment fitting in this category includes:

   a. Tank structures
   b. Box structures
   c. Large lightweight frame structures
   d. Smoke stacks

2. Equipment that is quite frangible (brittle) such that even moderately small relative motion of its parts would cause serious damage. Sample types of equipment in this category would include glass-lined tanks and pipes, other refractory-lined equipment such as boilers and furnaces, and equipment containing glass, which would be severely damaged if the glass breaks.

It is not clear at present whether the above classes of equipment would be more sensitive to the direct blast damage mechanism or to one of the other mechanisms. Note that some of the above equipment will have a very low W/A so that it will be quite vulnerable to impact by other equipment, wall fragments, and portions of the collapsing roof.

Collapse of the support structures in the class 1 equipment above is susceptible to calculation so that, with further work, estimates of the vulnerability of such equipment to direct blast can be made. Then this vulnerability can be compared with that from the other mechanisms. For the class 2 equipment, however, such calculations do not seem to be generally feasible with the current state of knowledge and it is believed that, until actual experiments are carried out, engineering judgment must be relied on to make estimates of the vulnerability.

Practical options for these classes of equipment ar limited; they are discussed in Part V.

OVERALL CONCLUSIONS REGARDING DAMAGE MECHANISMS

Equipment Inside Buildings

For equipment inside a building surrounded by other equipment, the primary mechanism for severe damage is expected to be translation followed by impact against other equipment or structural members of the building. Thus, the grouping of equipment for damage prediction should be based on those characteristics of the equipment that are important for this damage mechanism. As discussed earlier with regard to the velocity achieved under blast loading, this is the product DF where D is the dimension of the equipment in the direction of the blast motion in sq ft and F is the ratio of the average density of the equipment to that of steel. Note that another, and perhaps easier to visualize, way of expressing the product DF is in terms of W/A (specifically W/A = 500DF) where W is the weight of the equipment in lb and A is its cross-sectional area exposed to the blast in sq ft.

The blast wave parameter that controls the velocity is the dynamic pressure impulse (I_q), which in turn is determined by the peak overpressure, weapon size, and height of burst. The above relationships have been given in Figure II-2 in terms of the product DF, and they are replotted in terms of W/A in Figure II-9, which is a plot of the overpressure necessary to give the threshold for severe damage and that needed to assure severe damage as a function of the factor W/A assuming a 1 Mt weapon and height of burst to maximize 20 psi. Also shown on the figure are the approximate limits for light, medium, and heavy equipment as the terms have been used earlier in the discussion:

Light $W < 500$ lbs, $0.05 \leq F \leq 0.1$;
Medium $500 \leq W \leq 5000$ lbs, $0.1 \leq F \leq 0.2$;
Heavy > 5000 lbs, $0.1 \leq F \leq 0.3$.

Note that this assumes equipment that has an approximate cubical shape. It is interesting to note that there is only a factor of about two in pressure between the threshold and assured damage levels.

It should be recalled that the damage curves given in Figure II-9 are based on the following two assumptions:

1. No serious damage will occur for impacts of the equipment on a rigid surface at velocities of 10 ft/sec or less.

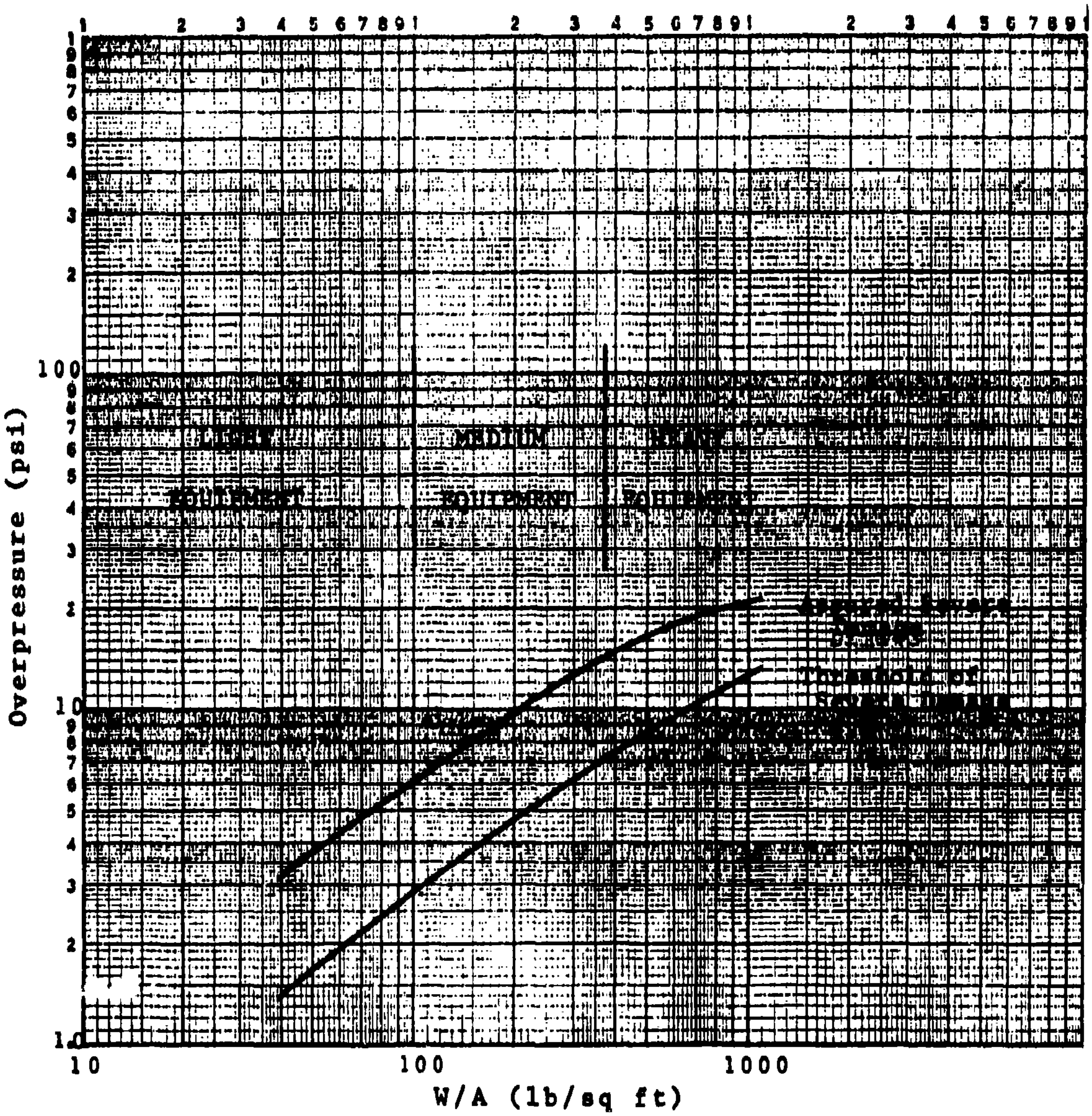


Fig. II-9. Overpressure Necessary for Severe Damage vs W/A, Where W is the Weight and A is the Cross-Sectional Area of the Equipment Exposed to Blast.

2. Severe damage is assured for impacts of the equipment on a rigid surface at velocities of 30 ft/sec or greater.

It is recognized that selection of these two velocity limits is based on engineering judgment and not on any significant body of experimental data since this does not exist.* In fact, one purpose of this report is to recommend a test program to provide a firmer basis for the damage predictions. It is also recognized that the procedures used up to this point in the discussion treat all equipment the same with regard to impact sensitivity, which is clearly an oversimplification; but again, not a great deal can be done about it until more experimental data are obtained. It does seem desirable, however, to consider the use of three classes of equipment sensitivity to impact, based on an intuitive feel for degree of ruggedness. At the extremes would be items principally constructed of heavy metal sections and devoid of delicate attachments such as gauges and controls as opposed to items mostly constructed of frangible materials like glass and lightweight plastics (e.g., desktop computers, communications equipment). The intermediate class would be something combining characteristics of the extremes.

To provide a starting point for hypothesis testing, tentative damage criteria for the three classes would use that already defined for an average, or Normal, sensitivity to impact and add a category on either side for High and Low sensitivity as follows:

1. High sensitivity

   velocity for threshold of severe damage - 7 ft/sec
   (corresponds to a drop height of 9 in.)

   velocity for assured severe damage - 20 ft/sec
   (corresponds to a drop height of 6 ft)

2. Normal sensitivity

   velocity for threshold of severe damage - 10 ft/sec
   (corresponds to a drop height of 1.5 ft)

   velocity for assured severe damage - 30 ft/sec
   (corresponds to a drop height of 14 ft)

---

* The data that exist are compared with the prediction methods in Section 4.

3. Low sensitivity
   velocity for threshold of severe damage - 20 ft/sec
   (corresponds to a drop height of 6 ft)

   velocity for assured severe damage - 40 ft/sec
   (corresponds to a drop height of 25 ft)

The curves defined in the above manner are shown in Figure II-10. At present, they are simply an untested hypothesis postulated for consideration for future use.

Equipment Outside Buildings

Equipment that is moved outside away from other equipment and buildings is, with certain exceptions, significantly less vulnerable to the blast wave. This is for three reasons:

1. The translation/impact mechanism, which was the controlling mechanism for most conditions, is no longer a factor as there is nothing to impact against (except the ground).

2. There is no possibility of roof collapse causing damage.

3. The likelihood of damage from flying fragments is eliminated or at least greatly reduced. It is assumed that in some cases it would be impractical to move the equipment far enough away to completely eliminate flying debris.

The major damage mechanism remaining, aside from the relatively low probability of wall fragment impact, is overturning with or without tumbling impact. The exceptions mentioned above are those items of equipment that are susceptible to overturning and that would be severely damaged in the basic overturning process. This is because the threshold for overturning is approximately the same as for translation/impact. As noted in the earlier discussion of overturning, this case is not considered very important because, if the effort is available to move the equipment outdoors, then it should be available to reorient most pieces of equipment so that they will not be severely damaged in the overturning process. This point is discussed more later under countermeasures.

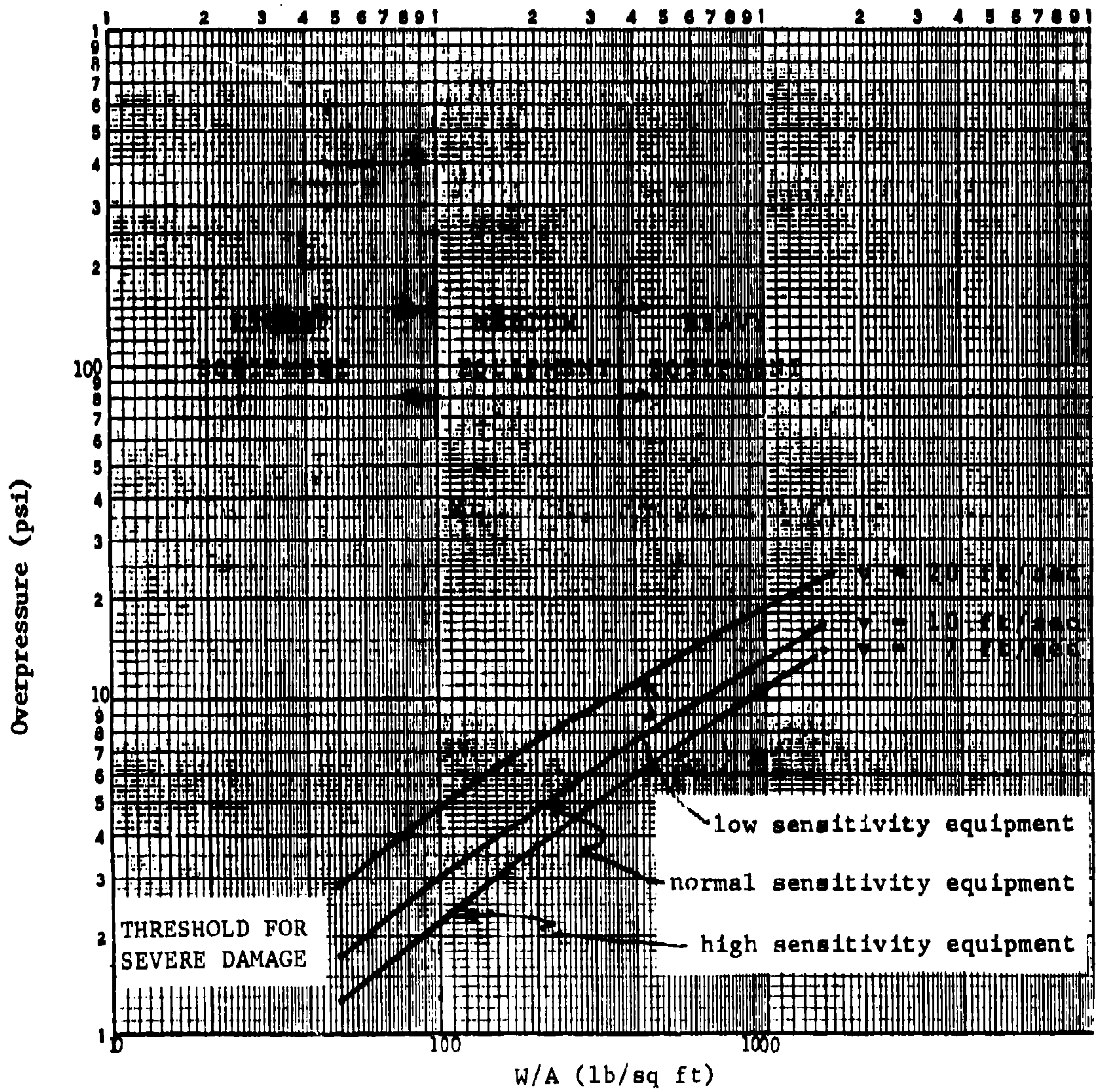


Fig. II-10. Overpressure Necessary for the Threshold of Severe Damage vs W/A for Various Sensitivities of Equipment. (Note, the curve for normal sensitivity is the same as the threshold curve in Fig. II-9.)

Considering tumbling impact next, it is clear that the mechanism for acceleration of the equipment is identical to that for the translation/impact case, so that again the W/A ratio of the equipment is the controlling factor. The difference lies in the nature of the impact process, which in place of being a single head-on (perpendicular) impact against a massive surface is a series of glancing impacts. If we again assume that the important factor in the impact process is the resulting velocity change and if we further assume that approximately equal velocity increments are lost on each impact, then it would appear that considerably higher initial velocities can be tolerated for the tumbling/impact case relative to the translation/impact case. If, for example, the threshold velocity for severe damage for tumbling/impact is three times that for translation/impact then it would be 30 ft/sec or the same as the assured severe damage level for translation/impact of normal sensitivity equipment. Now, from Figure II-9 this is roughly a factor of two higher in pressure. In Figure II-11 the tumbling impact case (assuming the factor of 3) is compared with the wall fragment case (8 in. brick). It can be seen that wall fragment damage could be important over the lower part of the W/A range. Note also the big spread between the threshold and assured severe damage curves; much greater than for the translation/impact case.

From the above it seems reasonable to expect that moving a piece of equipment outside away from other equipment and buildings and reorienting it to minimize overturning damage could double the overpressure level for the threshold of severe damage.

THERMAL EFFECTS

The thermal radiation released in a nuclear explosion is not considered in itself a direct hazard to industrial facilities. However, fires generated by the thermal radiation as well as blast-induced fires may constitute a significant threat.

The magnitude of the fire hazard depends not only on the characteristics of the industrial plant itself, but also on the nature of the construction surrounding the plant. With some obvious exceptions, of course, industrial plants as a whole are quite fire resistant. Structures are generally of non-combustible materials and, unless the products of the plant are combustible, there is little material onsite to burn. If, however, the plant is adjacent to residential or commercial areas,

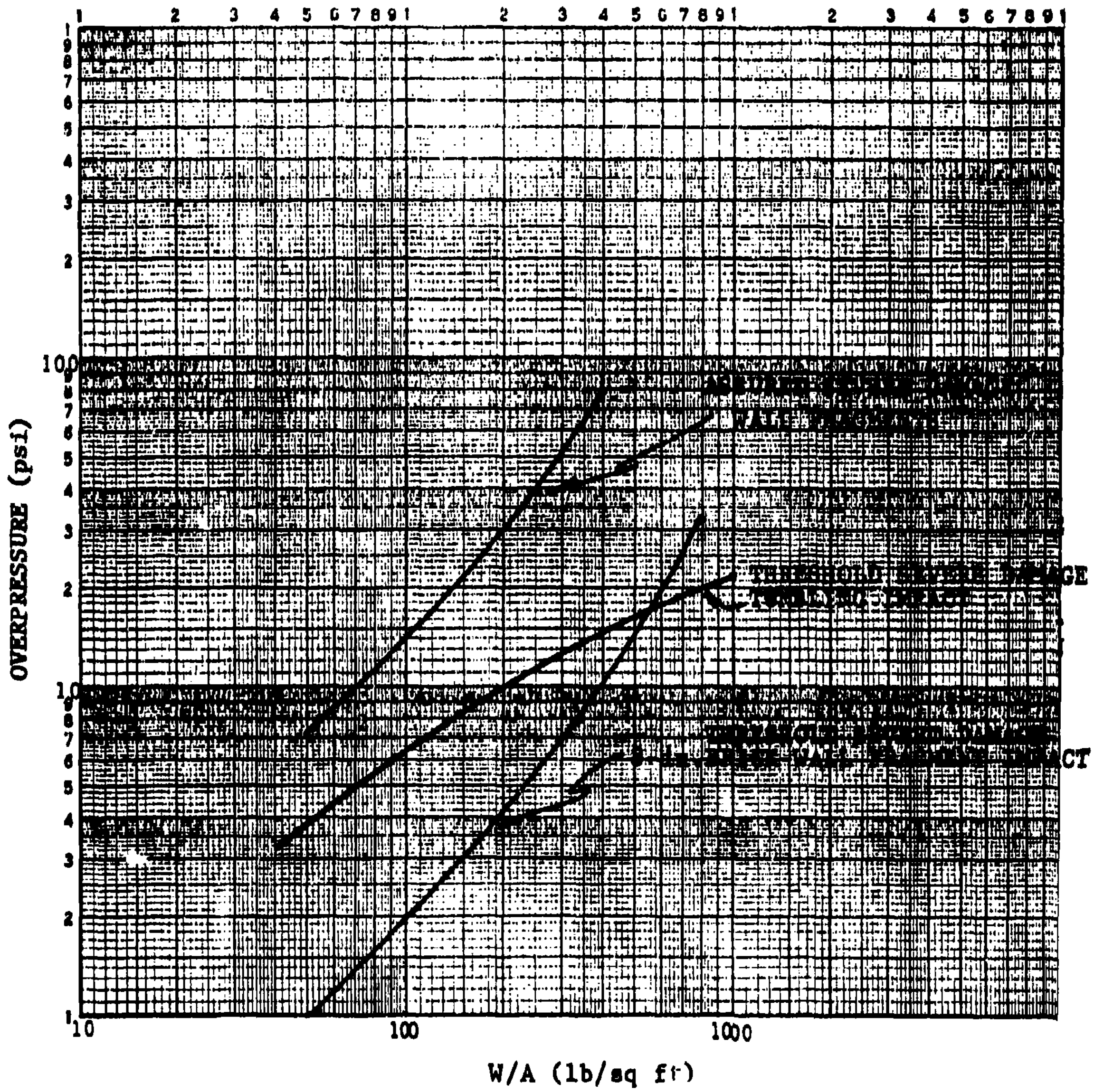


Fig. II-11. Comparison of Tumbling Impact Damage With 8-Inch Brick Wall Fragment Impact Damage.

sufficient combustible debris may be blown by the blast wave into the plant area to cause a serious problem.

Thus, in evaluating the fire hazard it is necessary to consider both that which results from off-site debris blown onsite (termed external fire hazard) and that due to onsite combustible materials (termed the internal fire hazard). The external hazard is quite general and is applicable to any industrial plant, while the internal hazard is dependent on the specific nature of the plant itself.

External Fire Hazard

The general nature of the external fire hazard is illustrated in Figure II-12 (see Appendix A, Section A-10). This figure shows the distance from adjacent urban areas within which a significant fire hazard is expected to exist as a function of incident overpressure.

Internal Fire Hazard

In any industrial facility processing combustible materials, considerable attention is devoted to fire prevention during normal operation. And in the absence of significant blast effects it would be expected that such facilities generally would be fire resistant also under nuclear weapons attack. The problem arises when the blast effects become sufficiently large to seriously damage structures and distribute combustible materials, including kindling fuels, throughout the plant area. At the blast levels where this occurs (about 10 psi) sufficient thermal radiation arrives after the blast wave distributes the kindling fuel to ignite it. Thus, fire ignition is assured.

At these high blast levels the only way to ensure no internal fire hazard is to remove the combustible materials from the plant site.

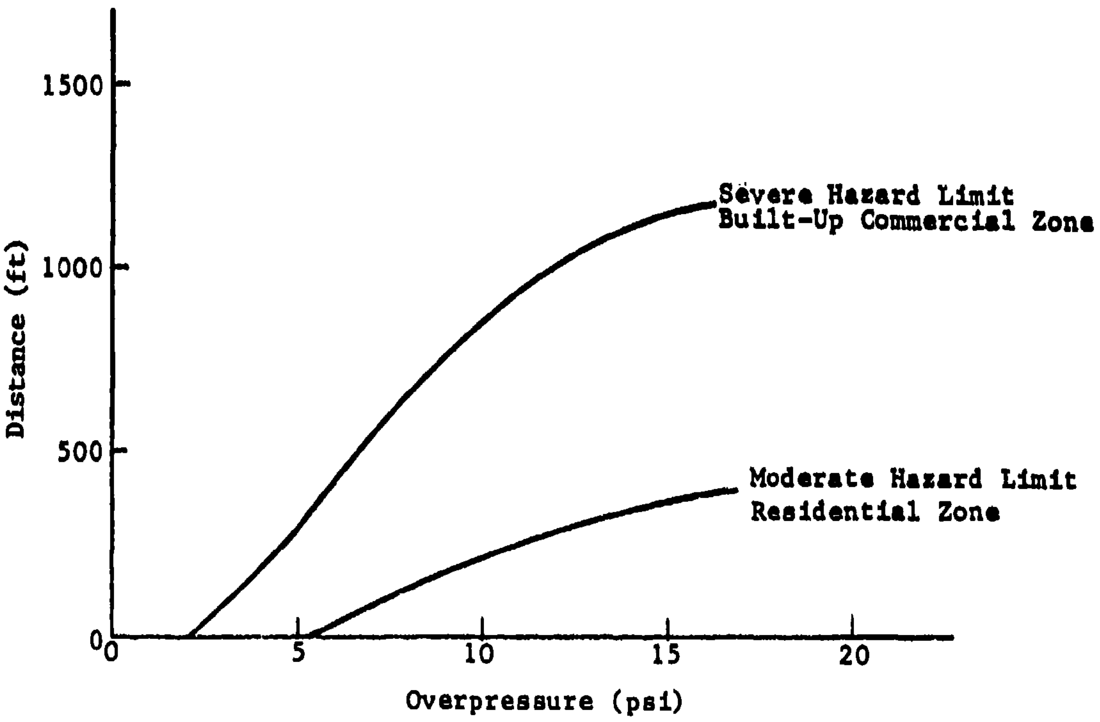


Fig.II-12. General Nature of Exterior Fire Hazard.

Section 3
CONSIDERATION OF COUNTERMEASURES

In the previous section the various damage mechanisms were identified and compared to determine which are the most important, and approximate procedures were developed for predicting the vulnerability of industrial equipment to these damage mechanisms. Although emphasis was placed on equipment in the as-is condition, many aspects of the work are applicable to the area of countermeasures, i.e., actions that can be taken to reduce the equipment vulnerability. In this section the subject of countermeasures is considered in further detail, and estimates are made of the degree of vulnerability reduction possible by each.

A list of the general categories of countermeasures is given below in a generally increasing order of effectiveness as well as a generally increasing level of effort necessary to implement the countermeasure. The first and last categories, protective housekeeping and miscellaneous, are exempt from this ordering.

1. Protective housekeeping
2. Reorienting
3. Isolating (move outside and away from other equipment and structures)
4. Clustering
5. Evacuating
6. Clustering with sandbag revetment or soil berm
7. Berming individually
8. Trenching
9. Packaging and anchoring
10. Burial
11. Miscellaneous

One problem that is almost certain to arise in some plants is the inability to move large, heavy items of equipment. For equipment somewhere between 10,000 lb and 20,000 lb, most facilities have neither the special handling equipment required nor the expertise necessary for moving such massive items. Even so, there are several hardening options that can be applied to these items.

PROTECTIVE HOUSEKEEPING

Under protective housekeeping a number of activities are performed. Among the most important of these are (Ref. 7):

Ensuring there is a minimum of loose material that can become potentially hazardous missiles under the dynamic pressure of the blast wave.

Removing or covering vulnerable gauges, controls, handles, and other fragile appendages to minimize the damage that may occur to the equipment under the action of missiles or other impact forces.

Unhooking power and fuel lines.

Removing flammable material.

Protecting critical equipment repair and maintenance records.

It should be noted that protective housekeeping is very important since it not only helps to minimize blast damage to industrial equipment but also reduces the fire effects of nuclear weapons on most industrial installations to the point where they can be neglected in relation to the blast effects. Exceptions include plants with combustible buildings or containing too much combustible raw materials or products such as paper, cardboard, wood, and gaseous or liquid combustibles to remove in the time available. Also excluded are plants immediately adjacent to highly built-up multistory commercial areas or other highly combustible plants. For such cases countermeasures 3, 4, 5, or 6 will have to be used to protect the equipment at overpressure levels of greater than about 5 to 10 psi to avoid the possibility of fire damage. Because of its importance and relative ease of implementation, it has been assumed in developing the damage prediction methods given in this report that as a minimum protective housekeeping will be carried out.

REORIENTING

By this countermeasure is meant reorienting or turning the equipment on its side to reduce the cross-sectional area exposed to the blast (and missiles) and to

reduce the effective height, which in turn will reduce the likelihood of overturning as well as reduce the impact forces in the initial overturning process. Consider for example a piece of equipment, which in its normal orientation is 2 ft by 4 ft by 6 ft high and weighs 4800 lbs. For the worst orientation, the area exposed to the blast is 24 sq ft (4 x 6) and the weight per unit area (W/A) value is 200. From Figure II-9 it can be seen that the pressures for the threshold of severe damage and assured severe damage are about 5 and 10 psi respectively. Now, if the equipment is turned on its side, the W/A value increases to 400 lb/sq ft and the pressure values to 7.5 and 15 psi respectvely, a 50% increase over the normal orientation.

Now, in its original orientation this piece of equipment is very susceptible to damage from overturning because its D/H (depth to height) ratio is 0.33 and the depth is only 2 ft. From Figure II-1 it can be seen that the minimum velocity for overturning is about 3.5 ft/sec. It also can be shown that the average impact velocity in the overturning process is $8(3)^{1/2} = 14$ ft/sec and the velocity of the top edge could be as high as $8(6)^{1/2} = 20$ ft sec. With the equipment turned on its side, the D/H ratio is 2 and the depth is 4 ft. This leads to a minimum overturning velocity of about 9 ft/sec, an average impact velocity of 8 ft/sec, and a top edge impact velocity of 11 ft/sec -- all very much more favorable values from a damage point of view.

To summarize, in its original orientation the equipment could overturn with a velocity as low as 3.5 ft/sec and at the threshold of overturning the upper edge of the equipment could impact the ground surface with a velocity as high as 20 ft/sec, a velocity twice that for the threshold of severe damage for normal equipment. Now, if this particular piece of equipment has even a moderately sensitive key element mounted near its top edge, then the equipment as a whole could be severely damaged in the overturning process. By turning the equipment on its side the minimum velocity for overturning was increased to 9 ft/sec, which is about 3 times the original value (and a value about equal to the 10 ft/sec taken as the threshold for severe damage for all impact cases). Further, the impact velocity of the top edge was reduced from 20 to 11 ft/sec -- again, about the same as the 10 ft/sec value. It is clear, therefore, that one of the major purposes of the reorientation is to minimize the occurrence of overturning damage. The other, of course, is to increase the pressure level for threshold and assured severe damage from translation/impact as described in the previous paragraph.

ISOLATING

This countermeasure means moving the equipment outside away from other equipment and buildings. By doing so this countermeasure eliminates damage from the translation/impact and roof collapse mechanisms and greatly reduces damage from flying fragments. The main damage mechanism remaining is overturning and tumbling impact. As discussed earlier the equipment velocity levels necessary to cause severe damage from tumbling impact are quite uncertain but it appears reasonable that they may be several times greater than for translation/impact. If tumbling impact damage occurs at three times the velocity level for translation/impact then the equipment could withstand about twice the overpressure level.

Note that this countermeasure would include the previous one, reorienting. Also, it will not be often that sufficient room is available to isolate equipment; a couple of hundred feet are required in all directions to accomplish this.

CLUSTERING

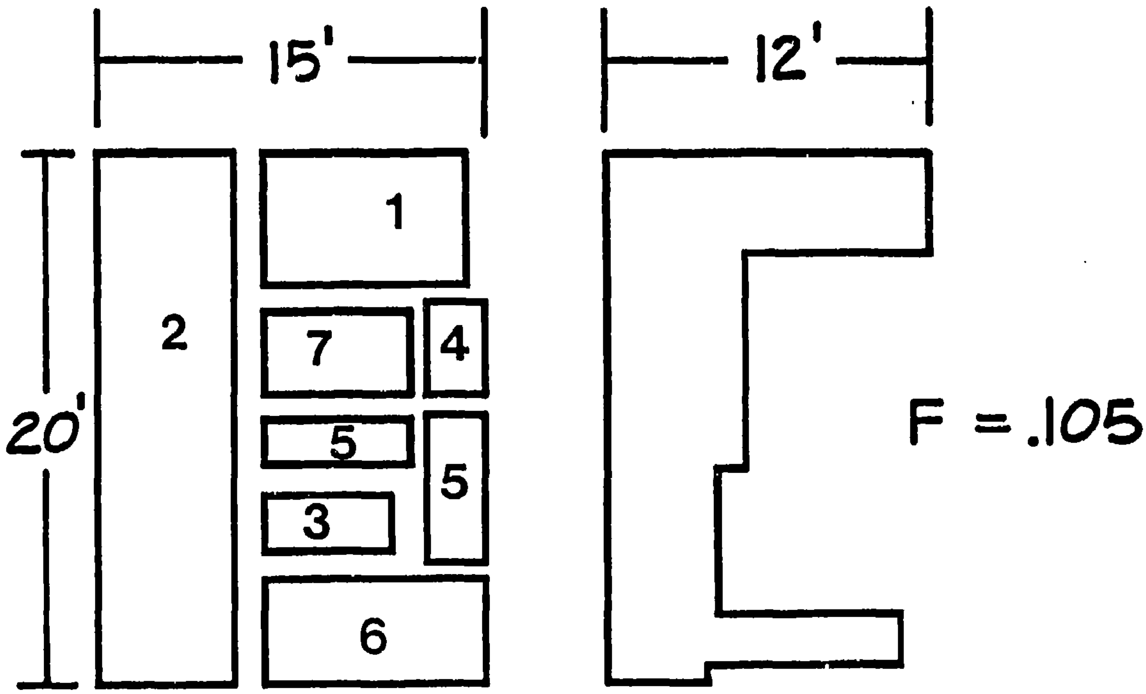
One of the most promising countermeasures where burial and evacuation are not feasible is to cluster the equipment in an open area (such as a parking lot) and to secure all items together by means of strapping, banding, or welding (Ref. 8). Providing that the cluster can be adequately secured as a unit, all elements within it will become very much less vulnerable than standing alone. First of all moving the equipment outdoors and away from other buildings and equipment greatly reduces its vulnerability as described above because the translation/impact and building collapse damage mechanisms are eliminated while the wall fragment damage is greatly reduced. This basically leaves only the overturning and tumbling impact damage mechanisms. The cluster vulnerability to overturning, however, is greatly decreased because the cluster has a much larger overall depth and D/H ratio.

Consider, for example, a cluster made from 16 pieces of equipment each being similar to the one used in the previous example (2 x 4 x 6 ft high and a weight of 4800 lb). Assume the equipment is arranged so that the overall cluster width and depth are just 4 times those of the original equipment or 8 x 16 x 6 ft high. For the worst case equipment orientation the D value increases from 2 to 8 ft and the D/H ratio from 0.33 to 1.33. This means the minimum velocity for overturning increases

from about 3.5 ft/sec to 11 ft/sec and the pressure necessary to achieve this velocity from about 1.5 to 10 psi.

In making the clusters it is better to have the width and depth of the cluster about the same, since the vulnerability needs to be considered for the worst possible orientation. This can be accomplished for the type of equipment described above using 18 individual items instead of 16 and the cluster would have a width and depth equal to 12 ft. For this cluster the D value (over the single piece of equipment) increases from 2 to 12 ft and the D/H ratio from 0.33 to 2.0. This means the minimum velocity for overturning increases from about 3.5 to 15 ft/sec and the pressure necessary to achieve this velocity from about 1.5 to 15 psi. If the equipment were reoriented so that the 4 ft dimension became the height then a 12 ft by 12 ft cluster using only 12 items of equipment could be used with essentially the same result as the former cluster using 18 items. Note that all of the foregoing examples have been simplified by ignoring the space necessary between equipment for buffers. Also note that the cluster does not need to be made of the same types of equipment. This was done in the above examples only for ease of illustration. A sample cluster actually assembled, but not tested, is shown in Figure II-13(Ref. 8). The equipment used are listed in Table II-5 (Ref. 8) and the survival levels of the cluster are compared to those of the individual equipment items in Figure II-14 (Ref. 8). Note that individual items are plotted against their individual values of F, while the cluster is plotted against its F value acting as a unit.

Theoretically clustering can be used to increase the threshold pressure for severe damage manyfold. In the two above examples, the increases were as much as a factor of 10. The limit to the size of the cluster is not really known at the present time. It is basically determined by the ability to hold the cluster together during the blast loading. Based on the results of the testing discussed in Section 4, Comparison of Prediction Methods with Existing Data, it would appear possible as a very minimum to hold together clusters having D values of about 10 ft using seatbelt webbing (8,000 lb tensile strength) at pressures of up to 20 psi. As an upper limit the D values are probably in the range of 20 to 25 ft and pressures in the range from 25 to 35 psi. However, as noted in the referenced section it is extremely desirable to conduct further experiments to confirm these limits. Note that if significantly larger clusters than the minimum mentioned above are to be used it will likely be desirable to first assemble the equipment into clusters of about the minimum size or smaller and then to assemble a few of the small clusters into one larger one. This



PLAN VIEW

ELEVATION VIEW

Note: Numbers on items correspond to Table II-5.
F is the value for the cluster acting as a unit (individual item values are given in Table II-5).

Fig. II-13. Cluster of Equipment Listed in Table II-5.

TABLE II-5: SAMPLE F VALUES FOR EQUIPMENT

Item	Equipment	Depth (ft)		Length (ft)		Height (ft)	Weight (lb)	Equivalent ρ (lb/ft^3)	F
1	Vertical Mill	5	x	8	x	7	40,000	142	.29
2	Horizontal Mill	5	x	20	x	½@12 ½@ 3	40,000	57	.11
3	Shaper	2½	x	5	x	3½	4,000	91	.18
4	Punch Press	3	x	3-3/4	x	5	3,800	68	.14
5	Turret Lathe	2	x	6	x	4	4,000	83	.17
6	Lathe	4	x	8	x	½@ 4 ½@ 3	4,000	36	.07
7	Compressor with water-filled air tank	3	x	6	x	5	3,960	44	.09
	Compressor	3	x	6	x	5	400	4.4	.009

ρ = equivalent density.

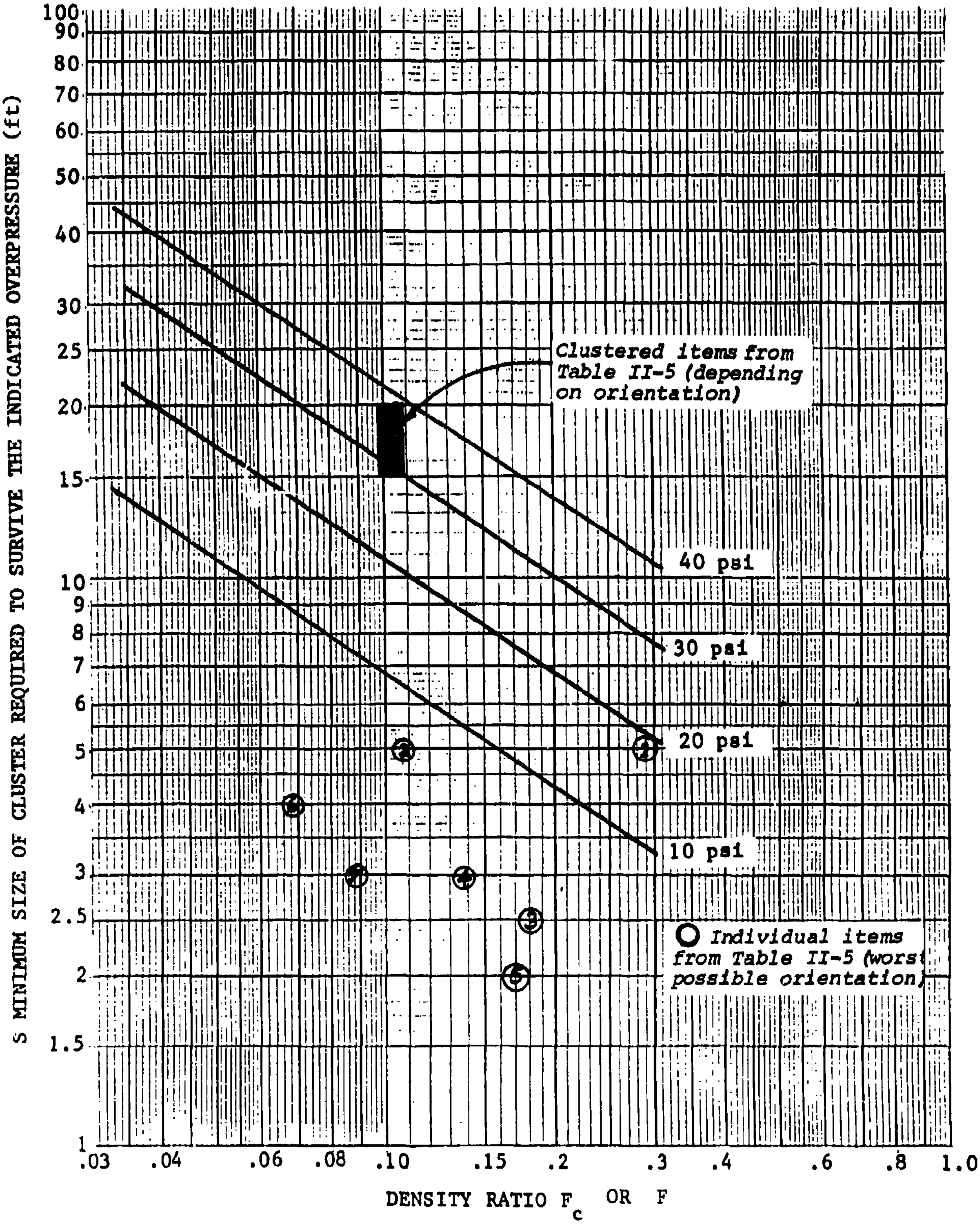


Fig. II-14. Survival Levels of Clustered Equipment for a 500 kt Weapon.

way, if the large cluster comes apart, there will still be some protection provided in the smaller clusters. As an example, if a 20 ft by 20 ft cluster is desired then it could be assembled from four 10 ft by 10 ft clusters.

EVACUATING

If sufficient manpower, materials handling, and transportation facilities are available on hand (they won't be something easy to acquire elsewhere in such a situation), movement of the equipment to a safe location outside the risk area is an ideal countermeasure. Those facilities that have items weighing in excess of 15,000 to 20,000 lbs, will be unlikely to be able to use this option for such equipment. Moving items in this size category safely and efficiently requires specialized handling equipment and expertise.

CLUSTERING WITH SANDBAG REVETMENTS OR SOIL BERM

This may prove to be a greater effort than evacuating. Where items are too large to evacuate, however, or where egress routes are limited, this option could prove to be a most important countermeasure. The addition of a sandbag or soil berm revetment to the full height of the equipment (a slope of roughly a 1 ft rise in 4 ft is desirable) will help to ensure that the cluster retains its integrity and increases its survivability at the same time (it will add to the cluster mass and it protects against airborne missiles). With the revetment or soil berm, it is estimated a cluster can survive 30 to 40 psi of overpressure. If the revetment or berm is raised three feet above the equipment height and the space inside filled with dirt, the countermeasure becomes an above grade burial, which may enable the equipment to survive 300 psi.

BERMING

A simple earth berm placed completely around each item of equipment will offer protection from both fragments and overpressure. If placed around several items together, it is necessary to restrain the equipment to prevent items from impacting each other. This method will enable equipment to survive at least 20 psi.

TRENCHING

A counterpart to berming, trenching is another method that will protect from both fragment impact and overpressure. Again, equipment so protected needs to be restrained to keep items from impacting one another; chain link fencing stretched over the trench and staked down has proved adequate. Trenching and berming complement each other in that the digging of the trench automatically provides soil for a berm to speed the overall hardening task.

PACKAGING AND ANCHORING

This involves placing stacks of material (e.g., lumber) around the equipment to provide stability while protecting against overpressure and missile impacts, and wrapping seatbelt webbing around the package and fastening this to expedient anchors to prevent movement under blast loading. Several promising anchoring methods have been tested on a limited basis; however, most of them require further testing and evaluation before their behavior can be guaranteed for megaton range weapons. The primary concern is whether erosion of the surface by the initial portion of the blast wave will weaken the anchors and cause them to fail. A summary of the results of the anchoring tests is given in Section 4.

BURIAL

This option will generally require the most effort (and equipment). In some instances it may be the only feasible option. Burial of equipment under a several ft thick layer of soil, preferably surrounded by crushable material, is one of the best countermeasures in the sense of providing the greatest blast protection in the risk area. Without special packing around the equipment this will enable many items to survive 40 to 80 psi; with crushable material around the equipment, items may survive 300 psi. The protection mechanism is the arching that can take place in dry soil to transfer load off a more compressible package (created by the crushable packing). The major problem that can be encountered with this measure is that arching will not occur if the soil becomes saturated. Therefore it is important to ensure that rainwater does not get into the soil (nor into the equipment). This requires isolation using plastic wrapping before the soil cover is added.

MISCELLANEOUS

Several additional countermeasures have been suggested and partially tested but not to the degree of the foregoing countermeasures.

One particular tested hardening scheme that can be suggested for use in protecting highly sensitive electronic gear is to put it in 55-gallon drums partly filled with sand and include these drums in a cluster designed for medium or heavy equipment. This scheme can readily provide protection to at least 20 psi.

Section 4
COMPARISONS OF SURVIVAL PREDICTIONS WITH EXISTING DATA

Only a relatively small amount of data are available concerning the effects of blast waves from nuclear weapons or large HE explosions on industrial equipment. However, they are useful to provide some kind of a check on the prediction methods described above. The data that are available include the following:

1. Nuclear effects on machine tools (Ref. 9)
2. Testing of shelter design and industrial hardening concepts at the MILL RACE event (Ref. 10)
3. Industrial hardening and population blast shelter tests at the DIRECT COURSE event (Ref. 11)
4. Industrial equipment tests at the MISERS BLUFF event (Ref. 12)

NUCLEAR EFFECTS ON MACHINE TOOLS

Test Arrangement

At three distances from GZ seven pieces of primary machine tools and four pieces of secondary production equipment were exposed to a 30 kt weapon detonated at a 500 ft HOB. Details are given in Table II-6.

Test Results

The blast effects on the equipment are given below and compared with what would be expected based on the general predictions discussed earlier. Note that at the 2,750 and 4,700 ft distances the equipment items were sufficiently separated so that there was no chance for them to impact each other or any part of a building. Thus, no translation/impact damage could occur, and there was no chance to compare damage from the translation/impact mechanism with that from impact by wall fragments.

Table II-6

DETAILS OF MACHINE TOOL TEST ARRANGEMENT

Distance (ft)	Incident Peak Overpressure (psi)	Type of Equipment	Equipment Weight (lb)
2750	11.6	Prentice engine lathe	7,000
"	"	Pond engine lathe	12,000
"	"	Cincinnati milling machine Model 2M1	7,000
"	"	Van Norman milling machine Model 26	10,000
4700S	5.1	HPM hydraulic press	49,000
6800B	3.0	Fray milling machine	3,000
6800A	"	"	"
6800B	"	50 gal. capacity stainless steel pressure vessel	4,100
6800A	"	"	"
6800B	"	Drying system steam oven 30 in. wide, 60 in. high, 108 in. long	----
6800A	"	"	----

Note that 4700S means that the press was shielded by a two-story brick building, 6800B means that the equipment was in a Butler building at 6,800 ft, and 6800A, in an Armco Steelox building at 6,800 ft. Note also that a concrete block wall 5 ft 4 in. high was built about 6 ft in front of the equipment at the 2,750 ft distance.

Prentice lathe--sheared 8 anchor bolts, moved approximately 9 ft, and turned on its side. The basic parts such as bed, base, pedestals, tailstock, and gear box were in good condition. Some damage occurred from flying debris (wall fragments). Hand wheels and control levers were broken off, but major components showed no significant damage. Overall it appeared that the damage was not severe.

The minimum pressure that permits overturning is 4 psi, which is much less than the actual overpressure of 11.6 psi and is consistent with the fact that the equipment overturned. The calculated sliding distance (for a $C_f = 0.5$) of 16 ft is somewhat larger than the observed distance of 9 ft. The estimated actual wall fragment velocity is 90 ft/sec and the effective velocity, 9 ft/sec. The implications of this will be discussed later in the summary of results.

Pond lathe--was not moved by the blast but suffered some damage by flying debris. Overall conclusion is that damage is light and reparable. The minimum overpressure for overturning is 22 psi, almost twice the incident overpressure, which is consistent with the fact that the equipment did not overturn. The effective impact velocity of the wall fragments is estimated at 4 ft/sec. The implications of this will be discussed later.

Cincinnati milling machine--was irreparably damaged. The main column of this machine was broken off near the base, and this allowed the upper portion to be taken away with the blast. After separation of the base and the upper portion it became evident that the main column casting had been cracked through approximately 60% of its area prior to the test; thus no conclusions can be drawn from this piece of equipment.

Van Norman milling machine--sheared off its 3 anchor bolts and moved 9 ft but remained upright. The degree of damage received from the flying debris is a little uncertain because in one part of the report it says that this equipment received rather severe damage from flying building blocks, but the overall conclusion of the report was that the damage to the equipment at 2,750 ft was not actually severe in nature and that it was reparable; so this is what will be assumed.

The minimum overturning pressure is 10 psi, a little less than the incident pressure but not inconsistent with the fact that the equipment moved 9 ft but remained upright. This is because the minimum pressure only means overturning is

possible but not assured. The calculated sliding distance of 5 ft is considerably less than the actual distance of 9 ft. The estimated effective impact velocity of the wall fragments is 7 ft/sec and the implications of this are discussed later.

HPM hydraulic press--showed no evidence of blast damage even though the brick house was completely demolished. Missile damage was very light. The minimum overturning pressure is 7.5 psi, significantly greater than the incident pressure of 5 psi; thus, the fact that the equipment remained in place undamaged was to be expected, particularly as it was shielded from the blast by the brick building.

Fray mills--The mill in the Butler building showed no operational damage even though this building was extensively damaged, but some damage occurred to the mill in the Armco building. This building was also extensively damaged and the collapsing structure broke the knee-elevating handwheel and moved the vertical spindle arrangement downward 38 deg. No comment was made as to how serious this damage was, but it was noted that damage by exposure to the weather as a result of building failure was the most critical condition, so it is assumed that the damage fell into the light category.

The minimum overturning pressure is 4 psi, which is greater than the incident overpressure of 3 psi, so the fact that the two mills remained in place is to be expected. The fact that one of the two mills was undamaged and the other only lightly damaged even though the structures were extensively damaged is consistent with the prediction method, which indicates that at overpressures where the other damage mechanisms, particularly translation/impact, are not operative only lightweight equipment is expected to be damaged by roof collapse and then only if impacted by a heavy structural member of the roof.

Pressure vessels and steam ovens--there was no significant damage to any of these items of equipment. There is insufficient information regarding their characteristics to permit calculation of the overturning pressures. It is noteworthy, however, that the collapsing structure did not damage this lightweight equipment.

Summary of Comparisons:

1. In all cases the calculated overturning pressure was consistent with the observed results.

2. None of the equipment at the 2,750 ft station incurred severe damage. There was minor damage from impact of fragments of the concrete block wall and it was stated or could be inferred that a large percent of this damage was received by fragile appendages and mechanisms on the exterior, generally of a non-critical nature and quickly reparable or replaceable. The estimated effective impact velocities ranged from 4 to 9 ft/sec compared with the 10 ft/sec selected earlier as the threshold for severe damage. This suggests that the 10 ft/sec effective velocity for wall fragments is safe as a threshold for severe damage since no severe damage occurred. The threshold for minor damage would be somewhat lower.

On the whole it is believed that the fact that only minor damage occurred supports the use of the effective impact velocity concept. This is because the alternative approach, treatment of the concrete block wall as a massive impact surface, would lead to considering the equipment impacting at 90 ft/sec against it, which is equivalent to dropping the equipment from a height of 125 ft onto the surface. It is hard to visualize any piece of equipment that could survive this impact without serious and likely irreparable damage.

3. The survival of even light industrial equipment in buildings that have been extensively damaged indicates that, at the low overpressures where the principal damage mechanism is limited to roof collapse, equipment can be damaged only if impacted by a heavy structural member of the roof.

4. There were some inconsistencies between the predictions and the test results in regard to the distance that the equipment moved. For the Prentice lathe the distance was predicted to be 16 ft while the actual movement was 9 ft, and for the Van Norman milling machine the predicted distance was 5 ft while the actual movement was 9 ft. Further, in both cases it was reported that the equipment seemed to have been lifted up, carried, and then gently set back down on the ground surface. The predictions assumed that the equipment would slide along the ground (or possibly tumble). One other factor that may enter in here is that the prediction took no account of the bolting down of the equipment. This could possibly reduce the initial velocity of the equipment and thus the travel distance. Bolting was not considered because it would complicate any generalized prediction method greatly; and at loadings sufficient to give severe damage it seemed that bolting was unlikely to have a major effect. Further consideration needs to be given to the phenomenon of the equipment being lifted and gently returned to the ground surface.

5. The last general comment regarding observation of postulated damage mechanisms is that there was no significant direct blast damage (i.e., non impact related damage) identified except for the Cincinnati milling machine, but this had a very large existing flaw in the casting and thus does not count. One minor bit of damage on the Pond lathe was suspected of being caused by the direct blast but this damage was unimportant. This gives some support to the postulation made in the prediction that this type of damage is generally not going to be of much concern.

TESTING OF INDUSTRIAL HARDENING CONCEPTS AT THE MILL RACE EVENT

A number of experiments using industrial equipment and equipment simulants were conducted at the MILL RACE event at the 20 psi overpressure level from an explosion of 600 tons of ANFO (ammonium nitrate-fuel oil) equivalent to about 1 kt nuclear. These experiments were primarily for evaluating various expedient countermeasures and fell into the following general categories:

1. Evaluation of the clustering concept
2. Evaluation of shielding
   a. Sand bag berms
   b. Trenches
3. Evaluation of soil anchors
4. Evaluation of fluid immersion to minimize effects of overpressure on electronic components

A few pieces of unprotected lightweight equipment were also exposed to the blast to help evaluate basic equipment vulnerability.

Of the tests the major ones that are quantitatively useful for comparing with the prediction methods are the clustering experiments. The others can be used only in a qualitative sense.

Clustering Experiments

These experiments were conducted using 55-gallon drums either full or 1/3 full of water as equipment simulants. They also helped evaluate the behavior of drums containing hazardous materials. These drums were exposed singly and in 3-drum and 7-drum clusters. Figure II-15 is a plot of the expected behavior of the cluster.

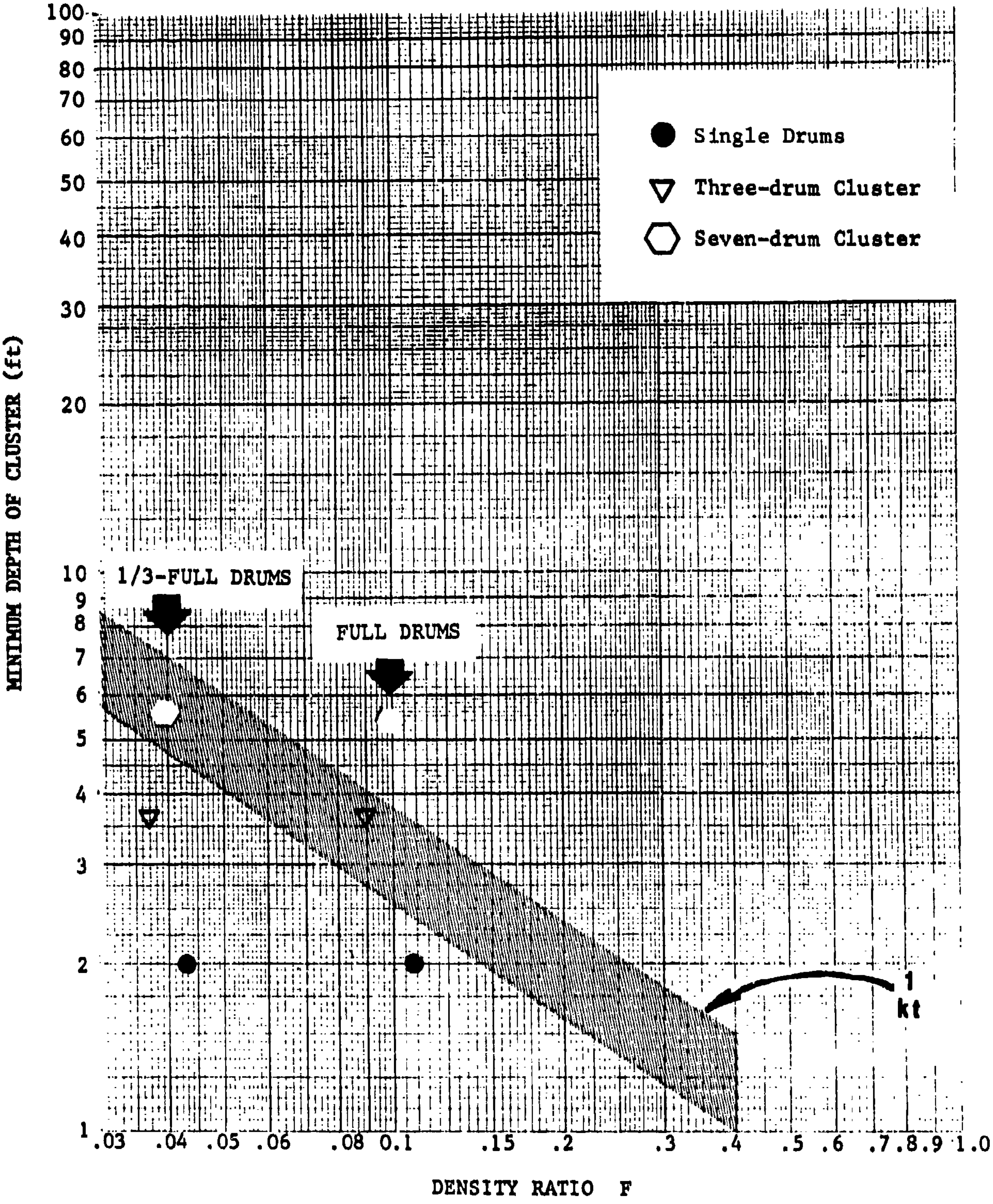


Fig. II-15. Twenty psi Survival Levels of Single and Clustered Drums for a Simulated 1 kt Test.

Based on Figure II-15, it would be predicted that the single drums, both full and one-third full, would overturn and move a distance greater than their depth; this, in fact, was what occurred.

Further, it would be expected that the full 7-drum clusters would not overturn nor slide a distance greater than their depth. This again is exactly what occurred. The one-third full 7-drum cluster is marginal and it did not overturn.

The full 3-drum cluster is also marginal; in one case the cluster overturned and in two cases it did not. The one-third full 3-drum array was expected to overturn and it did.

In summary, the clustering experiments verified the basic clustering concepts and in addition showed that it was possible to hold together 7-drum clusters under a 20 psi blast wave from a simulated 1 kt nuclear explosion.

Shielding Experiments

Two lightweight table saws and band saws were exposed in a trench. One of the table saws was picked up by the blast wave and impacted one of the band saws and in the process was seriously damaged - it broke its table casting, and bent its motor and sawblade mounting so that it was no longer serviceable. The remaining three items suffered only minor damage. It is believed that, if the items had been separated or restrained, no serious damage would have occurred.

Two lightweight band saws and one lightweight table saw were exposed to the blast between two 6-ft high berms oriented parallel with the blast wave front one on either side of a 5-ft wide level area. Both the berms and the level area were 12 ft long. Only one of the band saws survived with minor damage. The other band saw and the table saw suffered serious damage when they impacted each other. Again, it is believed that, if the equipment were isolated or restrained, no serious damage would have occurred.

Two lightweight band saws were exposed to the blast behind a berm of sandbags stacked 9 high (the berm had the shape of a right triangle with the sloping side towards ground zero). Neither saw was seriously damaged. One saw was immediately operable, and the other required only minor repair.

Anchoring Experiment

Two band saws were exposed to the blast, protected front and back by stacks of lumber bound together to the height of the saws with the open areas between the lumber stacks filled with sandbags and the entire package anchored to the soil with expedient soil anchors fastened by webbing. This stack was partially overturned but maintained its integrity and remained anchored. The two band saws recovered from the package suffered no damage and were immediately operable.

Unprotected Equipment Experiments

One table saw and two band saws were exposed to the blast unprotected except for sandbags piled against their legs. The band saw oriented end-on to the blast wave moved about 2 ft downstream and overturned. It was not damaged. The band saw oriented side-on to the blast was severely damaged; it was found in five pieces and was unrepairable. The table saw was translated 25 ft downstream and overturned but suffered only minor damage.

Prediction of the response of the equipment with the sandbags on their legs (six bags weighing 50 lbs each) is somewhat complicated because the sandbags can have a big effect on the response, but it is not known how long they remain in place. The reason they can have a big effect is that they greatly increase the weight of the equipment; for the band saw by a factor of 3 and for the table saw a factor of 3.6. Table II-7 compares the actual and predicted results for the three items of equipment for the two limiting cases: the sandbags come off very early and have no effect on the equipment response, and the sandbags remain in place throughout the loading pulse.

It can be seen from this table that the side-on band saw behaved as if the sandbags were not there in that it was severely damaged, which is expected to require a minimum velocity of about 30 ft/sec--just about the velocity predicted with no sandbags (32 ft/sec). The velocity predicted with sandbags is only 11 ft/sec. Further, the observed displacement of 24 ft is much closer to the 32 ft displacement predicted for no sandbags than to the 4 ft, with sandbags.

The table saw also acted largely as if the sandbags were not there. Its displacement was 25 ft compared to predicted values of 32 ft without sandbags and 2 ft with sandbags. In contrast to the band saw side-on, it suffered only minor damage. This is not inconsistent with the prediction method since the predicted velocity

without sandbags is 32 ft/sec, which is just slightly over the threshold for severe damage.

The band saw end-on behaved just the opposite, i.e., it acted as if the sandbags remained in place until the loading was over. This conclusion is based primarily on the small observed displacement of 2 ft, which agrees with that calculated with sandbags. The displacement without sandbags was calculated at 16 ft. No real conclusion can be drawn from the fact the equipment was not damaged since the calculated velocities for both cases (8 ft/sec with sandbags and 23 ft/sec without) were below the estimated severe damage threshold (30 ft/sec).

Table II-7

COMPARISON OF PREDICTED AND OBSERVED RESULTS
FOR SANDBAGGED TEST ITEMS

Equipment Item	**Pred Vel** (ft/sec)	**Damage** **Pred**	**Obs**	**Displacement** **Pred** (ft)	**Obs** (ft)
Band saw side-on without sandbags	32	th*- severe	severe	32	24
Band saw side-on with sandbags	11	minor	"	4	24
Band saw end-on without sandbags	23	minor	minor	16	2
Band saw end-on with sandbags	8	minor	"	2	2
Table saw without sandbags	32	th*- severe	minor	32	25
Table saw with sandbags	9	minor	minor	2	25

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* threshold of

INDUSTRIAL PROTECTION EXPERIMENTS AT THE DIRECT COURSE EVENT

Various industrial protection experiments were conducted at the DIRECT COURSE event, which was an explosion of 600 tons of ANFO equivalent to approximately 1 kt nuclear. The primary purpose of this group of experiments was to further verify the clustering concept by:

1. Testing of clusters of actual equipment under conditions similar to those for the clusters of simulated equipment (55-gallon drums) conducted at MILL RACE.

2. Testing of an actual equipment cluster inside a structure where it was exposed to flying wall fragments as well as the blast wave.

3. Testing of simulated equipment clusters (55-gallon drums) under a wider range of conditions than were investigated at MILL RACE including:
   a. Higher overpressures
   b. Larger clusters
   c. Wider range of tie materials

In addition to the equipment clusters, eight individual items of unhardened equipment were exposed at the nominal 20 psi pressure level to obtain reference data on equipment vulnerability. Also, two electronic power supplies were placed in 55-gallon drums and exposed at the same pressure level.

Equipment Clusters

Three clusters were tested. Each cluster consisted of nine metal-cutting bandsaws. Cushioning material consisting of automobile tires was placed between the saws, and the cluster was tied together with seatbelt webbing. Each cluster was about 3.5 ft wide with a depth, D, in the direction of the blast of 9 ft. The overall density of the array was about 17 lb/ft^3.

Equipment Cluster on Concrete Pad - This cluster was at the nominal 20 psi level; however, measurements made in line with this experiment but closer suggest that the pressures were considerably higher, possibly as much as 20 to 30 percent. It had been estimated that this cluster would translate approximately 3 ft and not overturn if the array maintained its integrity. For the 20 to 30 percent higher pressure the cluster was still not expected to overturn, but the displacement was

expected to be about 5 to 6 ft. The displacement observed was 6 ft and the array came apart to the extent that the first row of equipment was lifted over the second row. Post-test examination showed that, although the legs of the bandsaws were damaged beyond repair, eight out of nine of the saws themselves were operable with only minor repair.

Equipment Cluster on Dirt Pad - It was calculated that this cluster would also move approximately 5 ft for the impulse measured on the gauge line nearest this experiment. This is what was observed when account is taken of the displacing of the front row in the array over the top of the remaining two rows. Again, eight out of nine of the saws survived with only minor and easily reparable damage.

Equipment Cluster in Industrial Building - The purpose of this test was to determine the effects of debris (in this case, asbestos siding) on clustered equipment. The overpressure received at the building was 27 psi and the structure collapsed (an unexpected result). The cluster displaced approximately the same distance as those exposed in the open, but unfortunately this put it under one of the major structural members of the collapsing building, and six of the nine items were seriously damaged and could not be repaired.

Comparisons of Equipment Cluster Response With Predictions

None of the equipment clusters was expected to overturn providing that the cluster remained intact. However, there was partial failure of the fastenings and partial overturning for the two clusters in the open. On the whole, however, the cluster provided a good deal of protection to the equipment since 8 out of 9 items in each cluster survived with only minor damage. However, their behavior did emphasize the problems of fastening lightweight equipment together. In this case the deformation of the light sheet metal loosened the seatbelt webbing sufficiently to permit the front row of equipment to turn over onto the back two rows. It is believed that the one item in each cluster that was seriously damaged suffered in this fashion. For more sturdy equipment it is believed that this would not have happened.

The predicted displacements for all clusters were close to the observed ones when corrections were made for the 20 to 30 percent higher pressures received than predicted.

The prediction method indicates that lightweight equipment will receive serious damage if it is impacted by a heavy or major structural member of a roof and this is in fact just what happened to the cluster in the building. Six of the nine items received serious damage. It may be noted that the probability of a major structural member impacting a particular item of equipment is higher in this particular building, which was of an unusual design not typical of a normal industrial building, since it was built to withstand much higher pressures and thus the structural frame members were more closely spaced and massive.

Simulated Equipment Clusters

Simulated equipment clusters were exposed at three different ground ranges; nominal 20 psi, nominal 30 psi, and nominal 40 psi.

Nominal 20 psi experiments - Three 7-drum clusters were exposed with differing tie materials: 700 lb tensile strength nylon cord; 1,000 lb tensile strength nylon cord; and 4,000 lb tensile strength seatbelt webbing. The best estimate of actual pressure was 23 psi. Both of the nylon cord clusters came apart because of failure of the cord. The seatbelt webbing cluster survived. It displaced 1 ft compared to a predicted value of 1.75 ft.

Nominal 30 psi experiments - Five clusters with differing numbers of drums (two 14-drum, two 10-drum, and one 7-drum) were exposed. The best estimate of the actual pressure was 39 psi. The clusters all showed some degree of breakup, in this case due to drums losing lids and some of their contents and deforming so that the webbing loosened and released drums from the cluster. A 10-drum cluster on a concrete pad stayed mostly intact even though two of the drums partially deformed after losing lids. This suggests that more rigid bodies can be successfully clustered at this pressure level if bound with 8,000 lb tensile strength seatbelt webbing.

Nominal 40 psi experiments - Two 7-drum clusters and two 19-drum clusters were exposed. The best estimate of actual pressure is between 44 and 50 psi. All clusters broke up because of both deforming of the barrels and rupturing of the 8,000 psi seatbelt webbing when the drums did not deform.

Comparison of Simulated Equipment Clusters Behavior With Predictions

At the nominal 20 psi level (best estimate actual 23 to 25 psi) the 7-drum clusters were not expected to overturn, providing that the cluster remained intact.

And, this is in fact what occurred. The seatbelt cluster that remained intact did not overturn, and the two nylon cord clusters where the cord ruptured came completely apart.

At the nominal 30 psi level (best estimate actual 39 psi) the 7-drum cluster was expected to overturn, the 10-drum not to overturn but only marginally, and all larger clusters to not overturn. The only cluster to basically remain intact was a 10-drum cluster that did not overturn.

At the nominal 40 psi level (best estimate 44 to 50 psi) none of the clusters remained intact.

Overall Conclusions Regarding Clustering

All of the experiments support the basic clustering concepts. The only problem appears to be in making sure that the cluster maintains its integrity under the blast loading. The ability to hold a cluster together would appear to depend on the type of equipment in the cluster, the size of the cluster, the means for fastening it together, and the loading on the cluster.

Type of equipment - The experiments show that, for both the lightweight equipment used and the 55-gallon drums, deformation of the items caused partial or complete loss of integrity of the cluster. In the case of the equipment, it is felt that this could have been cured by welding braces on the frame to stiffen the equipment and in the case of the drums by using ones without replaceable lids. Actually strapping together medium or heavy equipment likely will be easier than for light equipment.

Size of cluster - Relatively little information is available on how large a cluster it is practical to make. Based on the light equipment cluster results the depth of the cluster can be at least 9 ft for loadings of at least 20 psi using the 8,000 lb seatbelt webbing. It seems likely that somewhat larger equipment clusters can be made and/or the same size used at higher pressures; however, further experiments are necessary before passing these limits too far.

Means for fastening the cluster together - The 8,000 lb tensile strength seatbelt webbing has been shown to be sufficiently strong up to about 40 psi for the 1 kt loading of MILL RACE and DIRECT COURSE. If the assumption is made that the

breakup of the webbing is due to the maximum pressure in the loading pulse then this same result would be expected for a 1 Mt explosion. It is believed that this is a reasonable assumption providing that the cluster is not near the limit of overturning. Here again, however, it would be desirable to devise some experiments to check on this assumption.

Loading on cluster - The maximum loading that a cluster can take is not really known but it is likely between 30 and 40 psi.

Clustering drums to protect hazardous materials using seatbelt webbing would likely be practical up to pressures of at least 25 psi (and possibly 35 psi) if the drums do not have replaceable lids or if the lids can be fastened so they do not come off.

Individual Unhardened Equipment Item Experiments

Table II-8 lists the 8 equipment items exposed at the nominal 20 psi level (actual 23 to 25 psi) along with their post-test condition and predicted behavior.

Note that the electronic power supply is so lightweight (i.e., it has such a low DF value) that it does not fit the conditions assumed in the calculation very well with regard to pure impulse loading. Once the velocity of the object becomes significant compared to the particle velocity of the shock wave, then the effective loading force is less than that given by a pure impulse loading. Somewhat arbitrarily the point at which this occurs has been assumed to start at 50 ft/sec. This is why the velocity is shown only as > 50 ft/sec and the displacement as > 80 ft.

All items of equipment were predicted to be severely damaged except the two band saws end-on. For these items the calculated velocity was almost exactly at the threshold of severe damage so that no firm prediction could be made. As the results turned out, these two saws received only minor damage. One other item, one of the power supplies, also survived with only minor damage. The other 5 items were severely damaged as predicted. The observed and predicted displacements were generally in moderate agreement; however, as seen in other experiments, the scatter in these results is rather large. It is interesting to note that the two band saws survived the calculated velocity of 32 ft/sec and displacements of 15 and 20 ft and one power supply a calculated velocity of >50 ft sec and displacement of >80 ft without being severely damaged. These results tend to confirm that the threshold for severe damage for tumbling impact (over dirt surfaces) is at least 30 ft/sec

because no item of equipment received a velocity less than this and was severely damaged.

Table II-8

RESULTS FROM UNHARDENED INDIVIDUAL EQUIPMENT ITEM TESTS

Equipment Item	Pred Vel (ft/sec)	Damage Pred	Damage Obs	Displacement Pred (ft)	Displacement Obs (ft)
Band saw side-on	45	severe	severe	62	25- 38
Band saw side-on	"	"	"	"	25-100
Band saw end-on	32	th*-severe	minor	24	15
Band saw end-on	"	"	"	"	20
Table saw	45	severe	severe	62	120
Table saw	"	severe	severe	62	?
Power supply	> 50	severe	severe	>80	80
Power supply	> 50	"	minor	>80	50

* threshold of

Electronic Power Supply Hardening Experiments

The two power supplies, which were of the same type as those tested in the unprotected equipment experiments, were placed in 55-gallon drums half filled with sand and anchored to the simulated equipment clusters at the nominal 20 psi level. One was also given protection from the static overpressure by placing it in a bath of alcohol inside a plastic bag in a depression in the sand. This unit showed no damage post-test while the other showed only minor and easily reparable damage. The results of this experiment suggest that delicate electronic equipment can be hardened to at least 20 psi in a simple and rapid fashion.

INDUSTRIAL EQUIPMENT TESTS AT THE MISERS BLUFF EVENT

The major purpose of the testing at the MISERS BLUFF phase II Event 1 was to demonstrate a comparison of equipment survival between an unhardened factory and a factory hardened by direct burial of all equipment (surrounded by crushable material) in place in the factory building. In addition, however, two large milling machines were exposed unprotected outside the building. The Phase II Event 1 was an explosion of 120 tons of ANFO equivalent to about 0.2 kt nuclear. The factories were exposed to peak overpressures from 300 psi (front face) to 210 psi (back face) while the mills were exposed to a peak overpressure of about 115 psi.

All the equipment in the hardened building survived with only minor damage except for one drill press while essentially all of the equipment in the unhardened building was severely damaged demonstrating very clearly that burial is a very good countermeasure.

Neither one of the mills was severely damaged although minor damage resulted from fragments generated from the destruction of the unhardened structure, which was closer to the explosion but off to the side of the mills. Mill #3 was calculated to achieve a velocity of about 11 ft/sec, which is only slightly larger than its calculated overturning velocity of 9.3 ft/sec. Thus, it is not surprising that the mill did not overturn since this is considered a marginal case. The calculated translation distance was 4 ft compared to the observed one of 3 ft.

Mill #4 was calculated to achieve a velocity of 22 ft/sec, which is very much larger than the calculated overturning velocity of 5 ft/sec, so that it was expected to overturn and it did. Since there was no object for the mill to impact against except the ground surface the fact that it did not get seriously damaged at a velocity of 22 ft/sec is not surprising since it has been estimated that the threshold for serious damage in tumbling impact is about 30 ft/sec. Overall, the behavior of the mills is consistent with the prediction method. This is interesting because the peak overpressure in this test was considerably higher than in any of the other tests.

Section 5
RECOMMENDED ADDITIONAL TESTING*

There are three basic areas in which additional study and experimental data are needed to improve the prediction of blast damage to industrial equipment and to provide countermeasures to protect such equipment. These are:

1. Motions of the equipment under blast wave forces

2. Responses of equipment to various impact processes

   a. Overturning/impact
   b. Tumbling/impact
   c. Translation/impact
   d. Fragment (missile) impact

3. Protective ability of countermeasures

MOTIONS OF EQUIPMENT UNDER BLAST WAVE FORCES

As discussed in Section 2 (and detailed in Appendix A, Section A-1) the basic equation of motion assumed for the development of the present prediction methods is:

$$v = C_d (A/m) I_q \qquad \text{(Eq. 1)}$$

where v = velocity achieved by the equipment under the blast loading
C_d = drag coefffficient
A = cross-sectional area exposed to the blast
m = mass of the equipment
I_q = dynamic pressure impulse

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* Many of the ideas for this section came from Ref 13.

This equation is based on the assumption that impulsive loading conditions apply, i.e., that the velocity the equipment achieves during the passage of the blast wave is negligible with respect to the particle velocity of the blast wave. This assumption should not be greatly in error for the peak object velocities of concern (which are significantly less than 50 ft/sec) considering that the peak air particle velocities of 5, 10, and 20 psi blast waves are 240, 425, and 760 ft/sec respectively.

The only real uncertainty in the above equation is the drag coefficent, and possibly the effective cross-sectional area if the object rotates during the loading. Evaluation of these two factors, which can be considered together, is the main objective of this portion of the proposed experimental program.

RESPONSES OF EQUIPMENT TO IMPACT PROCESSES

Three types of equipment impact and one type of fragment impact have been identified in Section 2 as being of primary importance. The equipment impact cases are as follows:

1. Simple overturning followed by impact on the ground surface

2. Tumbling resulting in multiple glancing impacts on the ground surface

3. Translation followed by vertical (or head-on) impact against other equipment or surfaces

The most serious of these impact mechanisms with regard to causing damage is expected to be the third one, impact against vertical surfaces. It has been assumed in the prediction methods presented earlier that the threshold of severe damage for average impact sensitivity equipment will occur when it is dropped from a height of 1.5 ft onto a rigid surface. This corresponds to an impact velocity of 10 ft/sec. At the other limit it has been assumed that serious damage is assured for this type of equipment if is dropped from a height of 14 ft, which corresponds to an impact velocity of 30 ft/sec. The assumptions made for low and high sensitivity equipment are given in the following table:

Degree of Shock Sensitivity	Threshold of Severe Damage		Assured Severe Damage	
	Drop Ht (ft)	Impact Vel (ft/sec)	Drop Ht (ft)	Impact Vel (ft/sec)
High	0.75	7	6	20
Normal	1.5	10	14	30
Low	6.0	20	25	40

It should be emphasized that the above assumptions were based on plausibility arguments rather than any significant set of experimental data as such data do not exist. The objective of the equipment impact portion of the program is to generate a set of data to replace the assumed ones given in the above table.

It is believed that all needed information about the simple overturning case can be inferred from the results of the vertical impact tests. This is partially true for the tumbling impact case also; it is believed, however, that some testing of this condition will be necessary.

The last type of impact process of concern is fragment or missile impact, which involves primarily fragmentation of the wall of a structure and subsequent impact of the fragments against an item of equipment inside or adjacent to the structure. Since such fragments are not massive like the surfaces considered above under equipment impact, an effective impact velocity concept was introduced (see Section 2 and Appendix A, part 8), which assumes that the equipment will punch through the wall and that the effective impact velocity of such a wall is the velocity given to the equipment by the wall impact under inelastic conditions. In other words:

$$V(e)/V(w) = W(w)/W(e)$$

where V(e) is the velocity of the equipment after impact by the wall

V(w) is the initial wall velocity

W(w) is the weight of the portion of the wall that punches out and goes with the equipment

W(e) is the weight of the equipment plus W(w)

The objective of the fragment impact portion of the program is to check on the validity of the effective impact velocity concept and, if it is not suitable, to obtain sufficient experimental data to develop new criteria.

PROTECTIVE ABILITY OF COUNTERMEASURES

It is shown in Section 3 that, although there are quite a few countermeasures that will reduce the vulnerability of equipment, there are only three basic types that will do so by a large amount. These are:

1. Evacuation
2. Burial
3. Clustering (with and without sandbag revetments)

The first two of these, evacuation and burial, are quite straightforward and do not need further experimental investigation. The limits to the usefulness of the clustering countermeasure, however, have not been fully evaluated. All of the experiments conducted to date show that the basic cluster concept is valid, providing that the cluster remains intact during the loading period. Further, it has been shown that clusters of up to at least 10 ft square will hold together at the 20 psi level from a 1 kt weapon. What remains to be determined is:

1. What is the upper limit in size for a cluster exposed at the 20 to 30 psi level?
2. How will the clusters behave under megaton range loadings?
3. How much help does the sandbag revetment give to a cluster?

CONSIDERATION OF SCALING

Motion Studies

As noted above, there is little question about the equations of motion; the pieces missing are the drag coefficients and possibly the effective cross-sectional areas. Experiments are necessary to obtain such information, but such experiments

do not need to be made at full scale using real equipment. Instead, they can be made on a model scale using equipment simulants. The use of model scale simulants for this type of testing will greatly reduce the costs of the experimental test program.

It should be noted that in these motion studies the main objective is to measure the velocity of the object after the loading is over, and knowing the input I_q to calculate the effective value of C_dA from Equation 1. In the modeling of the equipment the only concern is that the aerodynamic characteristics (primarily cross-sectional shape) be preserved and that too large a scale change not be used. This is because of possible local non-uniformities in the flow and because there is generally less acceptance of scaling involving too large a factor.

Response of Equipment to Impact Processes

In contrast to the motion studies the use of equipment simulants and scale models is not considered generally practical for studying the response of equipment to impact at velocities high enough to cause rupture of materials. Scaling can only be used with confidence when the basic relationships governing the response are known as in the case of object motion under blast loadings. The multitude of mechanical failure mechanisms that can be involved in equipment damage would be virtually impossible to describe with sufficient confidence to derive scaling relationships. Further, it is very possible that the various mechanisms will have different scaling so that a single scaling is not valid. For very simple impact cases, such as the impact of two rods end to end, the stress wave equations are known and it is possible to calculate, for example, what impact velocity is needed to exceed the compressive strength of the material and under what conditions sufficient tensile stresses can be generated at the opposite end to cause scabbing, i.e., tensile failure. Not very many sets of impact conditions, however, can be simplified in this manner.

For the above reasons it is believed that in general the response of the equipment to impact needs to be studied using actual items of equipment. Simulants can only be used if the changes from the real equipment are clearly such as not to change the impact sensitivity.

One possible exception to the above is if the equipment has a known response to a given acceleration. Then it may be possible to test an equipment simulant containing an accelerometer to determine the relationship between impact velocity

and acceleration. This probably will work only if the equipment is more or less peak acceleration sensitive.*

Note that for the equipment impact tests the recommended means for achieving the desired range of impact velocities is simply to drop the equipment from a range of heights. An actual blast wave is not considered necessary since the motion studies should give sufficiently accurate predicted velocities.

For the fragment impact tests, however, it is believed that explosive loading of the frangible walls (which are of most concern) will be necessary at least in the initial stages of the test program. This is because prediction of the fragment velocities is much less sure than prediction of the equipment velocities and because the velocities of concern are much higher than those for the equipment studies so that drop tests become much more difficult. Such explosively driven tests will require a facility such as the Shock Tunnel (Ref. 14) or its equivalent.

Further Evaluation of the Clustering Countermeasure

In evaluating the clustering countermeasure the three major objectives are:

> To determine what size clusters will maintain their integrity under overpressures greater than the 20 to 30 psi.
>
> To determine if the cluster behavior is different under megaton range loadings from behavior under kiloton range loading.
>
> To determine how much help a sandbag revetment gives to a cluster.

Although some help and guidance to the above questions may be obtained by testing with scale model equipment simulants, the majority of the testing will have to be done using nearly full scale equipment or simulants. This is for the same reason that real equipment needs to be tested for equipment damage - the exact mechanism of failure of the cluster is not known and thus cannot be scaled. It is anticipated however, that equipment simulants such as the 50 gal drums can be used in place of

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* Peak reading accelerometers (Impacto-Graphs) have been used in anthropomorphic dummies for studying impact effects on human beings.

real equipment since, in general, it is the failure of the cluster ties that is important and not the failure of the equipment inside the cluster.

Cluster testing should be conducted as a ride-along program on one or more large scale HE tests. Although it is desirable to obtain data from both a 1 kt and a 10 kt test, the latter is the higher priority, because considerable data have already been obtained on the 1 kt scale. If the large scale HE tests are not available, then some useful information can be obtained by tests conducted in the shock tunnel or its equivalent.

Testing Priority

It is believed that the highest priority for further study and testing is in the cluster evaluation area. The reasoning for this judgment is as follows. It appears generally desirable to protect equipment to at least 20 psi. Very little industrial equipment will survive anywhere near this pressure unless it is protected by one of the top three countermeasures (evacuation, burial, or clustering). And if it is protected by one of these three countermeasures, then it is largely immaterial what its unprotected survivability pressure is.

The second highest priority is in further study and testing of the basic survivability of industrial equipment. Such information is useful for those cases where it is not believed necessary to protect the equipment to pressures as high as 20 psi, which in turn would permit the use of some of the less effective countermeasures that generally do not protect to a given pressure but rather will increase basic survivability by some factor. Such information also will be useful for equipment that inherently has a high survivability pressure since here again one of the less effective countermeasures may be able to be used.

The lowest priority area is in further study and testing of the motions of equipment under blast loading. Basically, this area is as important as the equipment impact area; much more is known about it, however, and it is much more susceptible to calculation.

Note that, for all three of the above areas, the starting point for further work has been taken as the experimental test program. This is because it is believed that the analyses conducted to data have gone about as far as it is profitable without further verification and guidance from the experiments.

SUMMARY OF RECOMMENDED CLUSTER TEST PROGRAM

1 kt Test Scale

Plain Cluster

40 psi level -- 3 sizes - 2 fastening methods				-- total 6 clusters
30 psi level --	"	"	"	-- total 6 clusters
20 psi level --	"	"	"	-- total 6 clusters

Cluster with Sandbags

40 psi level -- 2 sizes - 2 fastening methods				-- total 4 clusters
30 psi level --	"	"	"	-- total 4 clusters
20 psi level --	"	"	"	-- total 4 clusters

Subtotal 30 clusters

10 kt Test Scale

Same as for 1 kt -- Subtotal 30 clusters

Grand total 1 kt and 10 kt: 60 clusters

Estimated Total Cost - $150,000.

Facilities Needed: 1 and 10 kt HE tests. It is assumed that the cluster tests are a ride-along program and do not bear any of the costs of conducting the tests.

SUMMARY OF RECOMMENDED EQUIPMENT IMPACT TEST PROGRAM

Approximately 30 different types of equipment as a minimum should be impact tested: approximately 15% of these fit in the high sensitivity class; 70% in the normal sensitivity class; and 15% in the low sensitivity class. It is estimated that it will be necessary to test between 5 and 10 samples of each type of equipment.*

The testing will start with impact velocities corresponding to the currently estimated threshold of severe damage, e.g., 10 ft/sec for normal sensitivity equipment. If no severe damage is obtained at this impact velocity the velocity will

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* There is insufficient information available at present regarding the statistical distributions of failures to estimate the number of tests required any closer than this.

be increased by increments (of, say, a value half way between the threshold velocity and the velocity assumed for assured damage - for normal sensitivity equipment this would be 20 ft/sec) until severe damage is obtained.

Although a variety of impact surfaces are possible, the great majority of the tests will be conducted by impacting against a massive concrete surface, since this is a very credible condition that tends to be on the conservative side.

Repeat tests on the same item of equipment will be conducted providing the damage incurred is less than severe and is reparable.

Estimated Total Cost - $300,000.

Facilities Needed: An arrangement for dropping equipment from heights up to approximately 20 to 25 ft onto a concrete slab. The costs of providing such a facility are anticipated to be small compared with the actual testing and analysis costs.

SUMMARY OF RECOMMENDED FRAGMENT IMPACT TESTS

The purpose of the fragment impact tests is to determine if the effective impact velocity concept is valid. If it is, then in general the equipment impact process controls the damage. For this reason selected examples of some of the types of equipment used in the equipment impact tests will also be used for the fragment impact tests.

It is estimated that initially some 10 different types of equipment will be tested with possibly up to 5 samples of each type of equipment.

The tests will be conducted in the Shock Tunnel (or equivalent facility) by placing a concrete block wall (or possibly a brick wall) between the equipment and the blast wave.

Estimated Total Cost - $175,000

Facilities Needed: Although there are other facilities that provide long duration loadings, the Shock Tunnel is the only known facility that will permit flying

fragments such as those resulting from the breakup of the concrete block or brick wall to be released inside the facility. The shock tunnel is currently not in operation and approximately $100,000 would be necessary to start it up.

SUMMARY OF RECOMMENDED EQUIPMENT MOTION STUDIES

As noted earlier these tests are to jointly evaluate the drag coefficient and effective cross-sectional areas of typical industrial equipment. Also as noted such tests can be conducted on a model scale with equipment simulants.

It is estimated that as a minimum some 20 to 30 different shaped equipment should be modeled for these tests.

Estimated Total Cost - $100,000

Facilities Needed: Any convenient shock tube can be used for these tests. The minimum size is about 1 ft square, although a somewhat larger cross section would be preferable.

PART III

CASE HISTORIES

PART III

CASE I

COMPANY "X" A TYPICAL HIGH TECHNOLOGY FIRM

FACILITY DESCRIPTION

Location and Local Hazards

This high tech firm began in the early 1960's when it was located on the peninsula 20 miles south of San Francisco to serve a variety of possible markets. Major hazards that threaten this peninsula site are earthquakes and nuclear attack, the facility having been located near the San Andreas Fault and in a region that TR-82 has indicated should be 16 psi.

Product and Markets

Initially, the company served the burgeoning aerospace industry, manufacturing its product and auxiliary equipment mainly for space research and space programs, then branched out to high energy physics and electronics industries. The principal product, an ion pump, enabled industries involved in vacuum research and vacuum technology to have ready access to high vacuums to support a variety of tasks. Applications include driving large vacuum chambers such as the aerospace industry requires to study effects of a space environment on operation of systems designed for space use; creating the vacuum needed in high energy physics for linear accelerators (which may require several hundred large units, each with a pumping speed of 400 l/s); and to supply complete bench-top vacuum systems to laboratories involved in sputter coating thin films for chips. These ion pumps typically enable vacuums of 10^{-11} torr to be achieved in very large chambers, or extremely high vacuums 10^{-14} torr to be achieved in smaller chambers.

Utilities

For production operations utility requirements are:

- o Electricity: 220/440 volt, 2,000 amp service;
- o Gas: comfort heat only;
- o Water: moderate supply for chem tanks;

The largest demand for power is to operate welding equipment. Each large ion pump unit requires 4 hours of welding time out of 15 hours of labor to construct. The large units are made up in batches of 20 to 25, the smaller ones are made up in batches of 100. A large finished unit will weigh about 300 lb and a small one around 25 lb. Materials are moved in, and finished products out, via commercial carrier. Thus, transportation capability onsite in an emergency is limited to two pickup trucks (and private automobiles of personnel).

Personnel Support

About 33 full time employees are required to operate the facility in a normal environment. Eighteen of these are not directly involved in production, but six of these are involved in research (and could provide additional backup resources for production in an emergency). A breakdown of the 21 positions that are directly involved in production or could provide backup capability is as follows:

Production:		
Manufacturing Engineer	------------	2
Production Manager	------------	1
Materials Coordinator	------------	1
Welders	------------	4
Sheetmetal workers	------------	3
Machinists (Journeymen)	------------	3
Floor Engineer	------------	1
Research & Development		
Mechanical Engineer	------------	3
Electrical Engineer	------------	2
Physicist	------------	1

Production Process

Figure III-1 indicates the facility production layout. The product requires attaching items formed onsite to products obtained elsewhere, including forgings that are contracted out and then machined onsite to required tolerances. The formed items are made of stainless steel sheet. Sheets are first sheared to size (see left hand side of Figure III-1), then holes with appropriate shapes (conic sections) are punched in the flat sheets to form openings where attached cylinders will intersect, the sheets rolled to form the cylinders, and flanges formed where needed on a break. Purchased

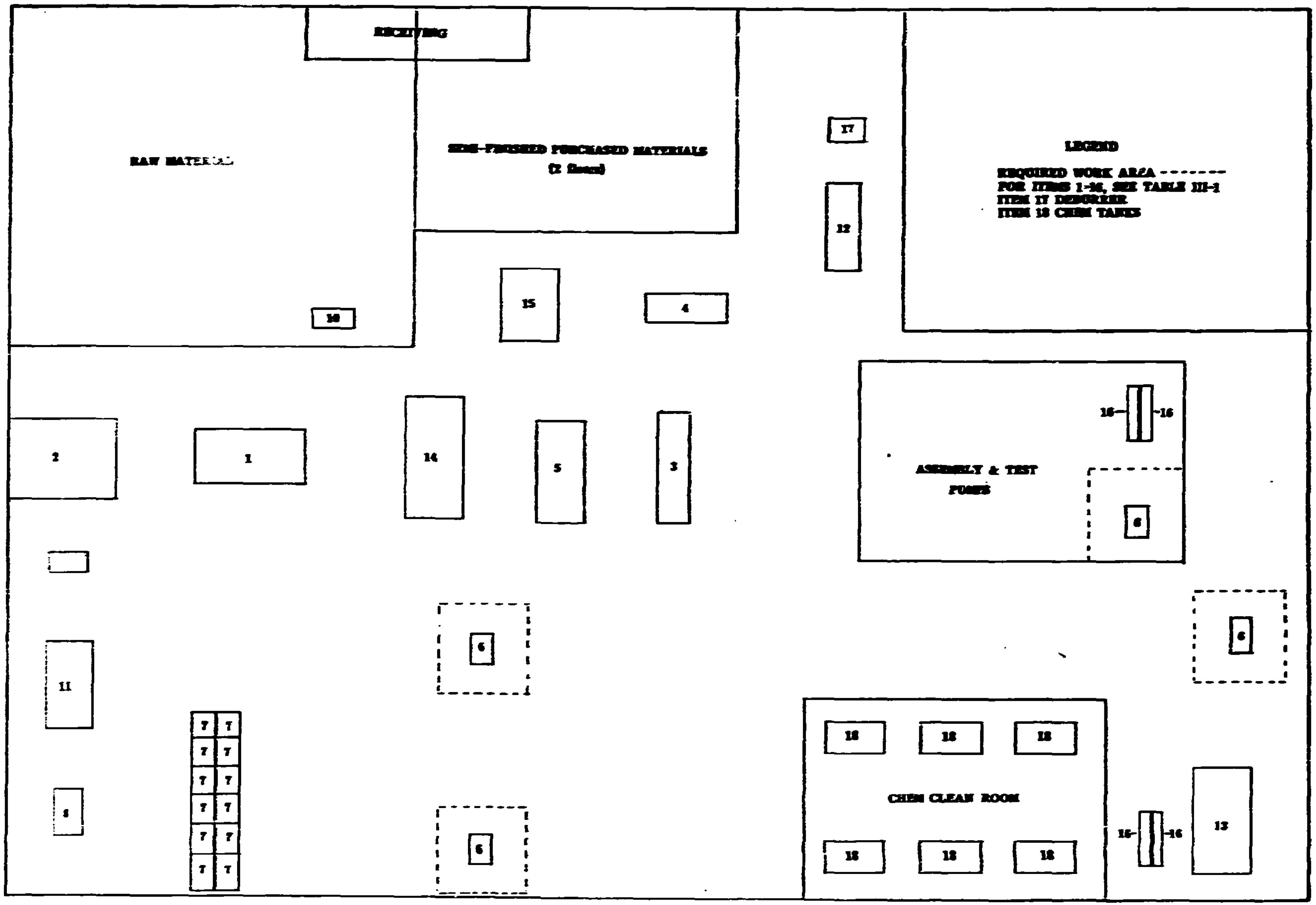


Fig. III-1. Plant Layout for Company X.

items (e.g., high vacuum "Kovar" seals and "McLeod Gauges") are then placed in position and welded. The machining of the special forgings to the desired shape and tolerances is a concurrent operation with the forming. Various stages of the machining required onsite occur where the lathes and milling machine are located (see Figure III-1). At the welder stations, the formed sheets and machined forgings are joined to meet specifications, then leak tested and chemically cleaned before placing them in the oven for baking out the occluded gases.

Priorities

The milling machine, the chucker, and some of the six welders and six tanks are not absolutely necessary. (The chucker makes six holes simultaneously - these could be drilled on the lathe; the milling machine is used to make the slot for leak testing simply because a milled slot looks neater for marketing; because welding is the bottleneck, one of the welders is a standby unit to keep production flowing in case a unit breaks down.) An electric forklift with a 3,000 lb capacity is sufficient to move materials about the shop, but this could be done by hand.

R & D Resources

In order not to interfere with production, the R & D group has its own machines that are used to manufacture modified units and for testing of new processes and new ideas. Clearly, R & D efforts may be expected to have a low priority in a post-disaster environment, in which case it is reasonable to anticipate that the machines assigned this department could be used for production.

VULNERABILITY/SURVIVAL ANALYSIS AND COUNTERMEASURE SELECTION

The analysis commenced with an evaluation of all the equipment. The forms used were those presented in Part I. In the material immediately following:

Table III-1 summarizes data for Company X on the "ESSENTIAL EQUIPMENT INVENTORY WORKSHEET."

Table III-2 is the "ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET" for processing the Table III-1 data to arrive at the SURVIVABILITY rating. For nuclear attack, this SURVIVABILITY rating is the maximum blast overpressure the item can survive without protection.

TABLE III-1: ESSENTIAL EQUIPMENT INVENTORY WORKSHEET, COMPANY "X"

ESSENTIAL EQUIPMENT INVENTORY WORKSHEET (E+RR = 5 OR LESS)

NUMBER	E+RR	EQUIPMENT NAME & DESCRIPTION	QTY	WEIGHT (W) in lbs	HEIGHT (H) in ft	LENGTH* (L) in ft	DEPTH (D) in ft	REMARK
1	2	HYDRAULIC PRESS / BRAKE	1	23,000	8.42	10.7	5.1	BOLTED TO FLOOR
2	2	HYDRAULIC SHEAR	1	30,800	6.67	10.6	8.2	BOLTED TO FLOOR
3	2	MULTIPLE SPINDLE DRILL PRESS	1	2,350	7.67	10.5	2.0	BOLTED TO FLOOR
4	2	ENGINE LATHE	1	3,200	4.4	8.3	2.5	BOLTED TO FLOOR
5	2	TURRET LATHE	1	5,300	5.0	10.1	5.3	BOLTED TO FLOOR
6	4	LEAK DETECTOR	1	440	3.2	2.4	1.7	ON CASTERS
7	4	TIG WELDER	6	476	2.3	2.8	1.8	FREE STANDING
8	2	SPOT WELDER	1	200	4.7	3.3	2.0	BOLTED TO FLOOR
9	3	POWER ROLL BENDING	1	1,170	4.5	7.8	1.6	BOLTED TO FLOOR

*Use Longest Horizontal Dimension

TABLE III-1: ESSENTIAL EQUIPMENT INVENTORY WORKSHEET, COMPANY "X" (contd)

ESSENTIAL EQUIPMENT INVENTORY WORKSHEET (E+RR = 5 OR LESS)

NUMBER	E+RR	EQUIPMENT NAME & DESCRIPTION	QTY	WEIGHT (W) in lbs	HEIGHT (H) in ft	LENGTH* (L) in ft	DEPTH (D) in ft	REMARK
10	3	BANDSAW	1	670	6.0	3.7	2.0	FREE STANDING
11	3	HYDRAULIC PUNCH PRESS	1	250	6.0	3.7	2.0	FREE STANDING
12	4	FORKLIFT	1	5760	6.4	9.4	3.2	MOBILE
13	4	OVEN	1	2850	6.0	10.0	5.0	FREE STANDING
14	4	CHUCKER	1	10,200	6.4	12.1	5.0	BOLTED TO FLOOR
15	5	HORIZONTAL MILL	1	5,830	7.9	5.9	5.9	BOLTED TO FLOOR
16	5	VACUUM PUMPS	6	830	2.4	3.2	1.9	FREE STANDING

*Use Longest Horizontal Dimension

TABLE III-2: ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET, COMPANY "X"

ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET

NUMBER	EXPOSED AREA IN SQ FT	WEIGHT/UNIT AREA IN LBS/SQ FT (W/A)	DENSITY FACTOR (F) = 0.002W/DHL	SURVIVABILITY SEE TABLE*
1	90.1	255	0.100	6
2	70.7	436	0.106	8
3	80.5	29.2	0.029	1
4	36.5	87.7	0.070	3
5	50.5	105	0.040	3
6	7.7	63.6	0.075	2
7	6.4	74.4	0.082	2
8	15.5	12.9	0.013	1
9	95.1	33.3	0.042	1

*Where W/A falls between listed values, use S for the smaller listing

VULNERABILITY/SURVIVABILITY TABLE

W/A	S
30	1
60	2
110	3
160	4
220	5
280	6
360	7
440	8
530	9
630	10
760	11
900	12
1100	13
1300	14
1500	15

TABLE III-2: ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET, COMP. .Y "X" (contd)

ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET

NUMBER	EXPOSED AREA IN SQ FT	WEIGHT/UNIT AREA IN LBS/SQ FT (W/A)	DENSITY FACTOR (F) = 0.002W/DHL	SURVIVABILITY SEE TABLE*
10	22.2	30.2	0.030	1
11	22.2	11.3	0.011	1
12	60.2	95.7	0.080	3
13	60.0	47.6	0.019	2
14	77.4	131.8	0.083	4
15	46.6	125.1	0.042	5
16	7.6	109.2	0.160	3

*Where W/A falls between listed values, use S for the smaller listing

VULNERABILITY/SURVIVABILITY TABLE

W/A	S
30	1
60	2
110	3
160	4
220	5
280	6
360	7
440	8
530	9
630	10
760	11
900	12
1100	13
1300	14
1500	15

The survivability ratings in Table III-2 indicate quite clearly that none of the items of equipment at Company X would survive the expected overpressure of 16 psi. Consequently, if the equipment is to be hardened so that it can survive, an analysis of countermeasures must be conducted to determine what is workable (that is, both feasible and practical) at this facility.

ASSESSMENT OF ALTERNATIVE METHODS FOR HARDENING TO TARGET OVERPRESSURE

Introduction

Every facility must deal with the fact that one or more of the possible hardening options may not be feasible or practical; such options need to be weeded out quickly. (For example, at Company X, the site has a high water table so burial belowgrade is an obviously undesirable alternative.) A frequent occurrence is that weights of equipment are incompatible with materials handling and transporting capabilities onsite so that, even if movement is feasible, it isn't practical unless some prior arrangement can be made for the necessary equipment. (A risk here is that, unless some mutually beneficial consideration exists that is critical to both parties to the arrangement, in the face of a serious emergency one of the parties may simply ignore it.) Limitations of the sort just described will be facility-specific so that it isn't possible to lay out all problems and solutions for every possible circumstance. Consequently, it is up to the individual facilities to identify feasible options that are practical. The analysis of hardening alternatives at Company X follows.

Evacuation

For evacuation to be successful, the following conditions must be met:

1. Adequate loading and transportation facilities must be available.
2. A safe area must be identified for evacuation to be meaningful.
3. There must be reasonable assurance that the route from the industrial plant to a safe area is open and can be negotiated in the required time (loading and moving must be completed in 3 days total time).

As the first requirement cannot be met for all the equipment at this facility with resources at hand, evacuation cannot be applied as a general countermeasure, here.

The problem at Company X is that three of the items of equipment (see Table III-1) weigh more than 10,000 lb while materials handling and transportation resources to deal with anything over 3,000 lb are not onsite. (Onsite resources are limited to the 3,000 lb capacity forklift and 2 pickup trucks with maximum load capability of 3,000 lb each.)

Although all of the remaining items of equipment at Company X could be moved fairly readily without special handling equipment and expertise, it would require one or two large trucks to accomplish in a single trip. Technically, several round trips with the pickup trucks could do it, but this is not likely to be practical for the following reason. In the face of a threat of an imminent disaster the return trips would be against a flow of traffic likely to be especially heavy, and probably using all lanes for the exodus as well. This version of the option does not, therefore, seem to offer a high probability for success and must be considered impractical. Another evacuation scenario that may prove more practical is to move the equipment out with a one way trip on a large truck, but this requires arrangements to be made for space on a truck leaving the local area. There are two negative aspects to this option. It lacks a high level assurance of success because resources from outside the plant are required, and the problem of how to deal with the large items of equipment that are not easily moved remains.

Burial

Even if there were not a high water table problem at Company X, because of the three very heavy items of essential equipment, the inability either to load them or to transport them with resources on hand would make their burial belowgrade impractical. Consequently, to apply the burial countermeasure to these items requires use of the abovegrade technique (this can be done with the equipment left in place, or pushed together on the floor). It will require a minimum of 100 tons of soil or 4,000 sandbags to bury them above grade. Obviously, without soil material onsite or nearby, this alternative would not be feasible either. Fortunately, a great deal of soil is accessible only several hundred yards from the facility. On further consideration, it is apparent that 60 to 90 trips, each with a full pickup truck, would be required to move enough soil to the site, and at least 60 man-hours would be required to do this, assuming the soil were loose. If the soil were hard, it might require two or three times this much time, or nearly 3 to 4 man-weeks for just these three items. Therefore, if there is a faster hardening option, it should be applied. Clustering is likely to be a faster alternative. If it proves to be effective, it is not only faster but

better from the standpoint that it solves the problem of what to do about some of the other equipment that must be saved.

Clustering

The clustering countermeasure seems to offer the most practical all around solution at this facility. (There is even welding equipment onsite to enable a frame of steel channels to be welded around the cluster to ensure it acts as a unit.) To achieve the dimensions necessary for cluster survival, more equipment would be needed than just the three heavy objects. To maintain the integrity of the cluster, objects that collapse or distort easily should not be used, or the cluster may break up as a result. For example, an oven would be a poor choice for a cluster as it has little structural strength and would quickly collapse under load. Generally speaking, the greater the F value (an F of 1.0 is a solid block of steel) the less likely collapse or distortion will occur. Even solid wood with an F of 0.10 is acceptable because it will not collapse and will distort only a little. However, as F values get down around 0.05 or lower, this generally indicates either very lightweight material or empty cabinetry. Either of these conditions could result in collapse of the object (though occasionally the cabinetry may be made of heavy enough steel plate that it would distort very little). Thus, equipment with an F factor lower than 0.10 should be considered carefully for its acceptability. An additional indicator that may help is what would happen if the object in question were placed between a bulldozer and one of the heavy freestanding items of equipment, and then both objects pushed across the floor. If the item in question will hold up for this, it is likely to survive well enough to be used in a cluster, but if it would distort or collapse it should not be included.

An examination of the equipment in Table III-1 at Company X was made to see what should be deleted from a cluster as unsuited; these items are indicated in Table III-3. It is important to note, here, that even though nonessential items are not listed on Table III-1, it may be worthwhile when considering the clustering alternative to include some of them. There are at least two good reasons for this: their inclusion may be necessary to have enough items to make up a cluster large enough to survive, and benefits may be obtained by putting nonessential items around the perimeter of the cluster to serve as buffers against missile and impact damage. To protect essential items unsuitable for clustering, some other alternative must be used for hardening them (this will be taken up later). The cluster option was evaluated at Company X with all suitable items of essential equipment included (these are identified in Table III-4).

TABLE III-3

EQUIPMENT UNSUITABLE FOR CLUSTERING

Equipment Item	Survivability (psi)	F Factor	Weight (lb)
1. Band Saw	1.3	0.030	670
2. Spot Welder	1.0	0.005	200
3. Oven	1.5	0.019	2850
4. Deburrer	1.0	0.017	125
5. Chemical Tanks	1.3	0.027	720
6. Power Roll	1.0	0.042	1168

TABLE III-4

CLUSTERED EQUIPMENT

Equipment Item	F Factor	Floor Area (A_f) (sq ft)	($F \times A_f$)
Hydraulic Press	0.10	55	5.5
Hydraulic Shear	0.11	87	9.6
Hydraulic Punch Press	0.21	33	6.9
Engine Lathe	0.076	19	1.4
Turret Lathe	0.040	53	2.1
Horizontal Mill	0.039	38	1.5
Leak Detector (2)	0.076	8	0.6
TIG Welder (4)	0.129	20	2.6
Electric Forklift	0.059	31	1.8
Chucker	0.053	60	3.2
Vacuum Pump (2)	0.138	8	1.1
Drill Press	0.04	21	0.8
	-----	---	----
	1.072	433	37.1

Average F Factor for the 12 items of equipment listed = 1.072/12 = 0.089

Weighted Average F Factor = 37.1/433 = 0.086

A cluster of the items listed in Table III-4 could be made into an array roughly 19 feet by 24 feet and having an average F = 0.086. From Figure III-2 (Figure V-8 from Part V) with 19 feet taken for the size (the size S in Figure III-2 is always the cluster minimum dimension), this cluster is expected to survive 32 psi; this is nearly double the PE = 16 value taken from TR-82. Though a 100% cushion is not really required, a larger array than necessary (with its higher survival capability) may be beneficial, to cover judgmental and targeting errors. There is a proviso, here, that one can be assured the array will hold together. Generally, as the dimensions of an array get larger (and also as the number of small objects in it increases) the more difficult it is to tie together as a unit to make it work. If the resources and ability exist onsite to weld a framework around the cluster, larger arrays will be possible (but studies have yet to be conducted to determine technical and practical limits).

If all the R & D equipment at Company X is added to the cluster, then F would become 0.071 and the array size would increase to 26 feet by 24 feet. The result of these changes makes the minimum size S = 24 feet so that the cluster survivability becomes slightly over 35 psi according to Figure III-2. In the event the R & D equipment is added, it would be preferable to locate it around the perimeter to provide a buffer for missile and other impacts (though only two sides would be so protected). Because the company is located with a bay on one side, it would be unlikely for the blast to come from that direction, and the buffer items placed at 90 degrees to this face would be especially likely to work successfully.

To help ensure the cluster remain a unit, 6 inch channel (between 15 and 16 lb per foot) should be used to form a box around it at elevations roughly located at the third points of the cluster height and at the top. These bands will need standoffs (also best located at the third points along each face) to keep the two separated and about 2 ft apart. Figure III-3 indicates what this box system would look like. The steel requirement for the two bands would be for twelve 6-inch channels 26 ft long and weighing around 390 lb each (about $75 per channel). Sixteen standoffs would be required, each being about 2 ft long. Four-inch, 7.25 lb channel would be adequate for this purpose at an additional weight of about 240 lb of steel (costing another $7[illegible] including cutting).

To complete the cluster, about 220 linear feet of 9 Ga. 6 ft chain link fencing material (not onsite, but available at $2.65 per lineal foot) is needed to provide missile and fire protection. A layer of this fencing material around the perimeter tacked to

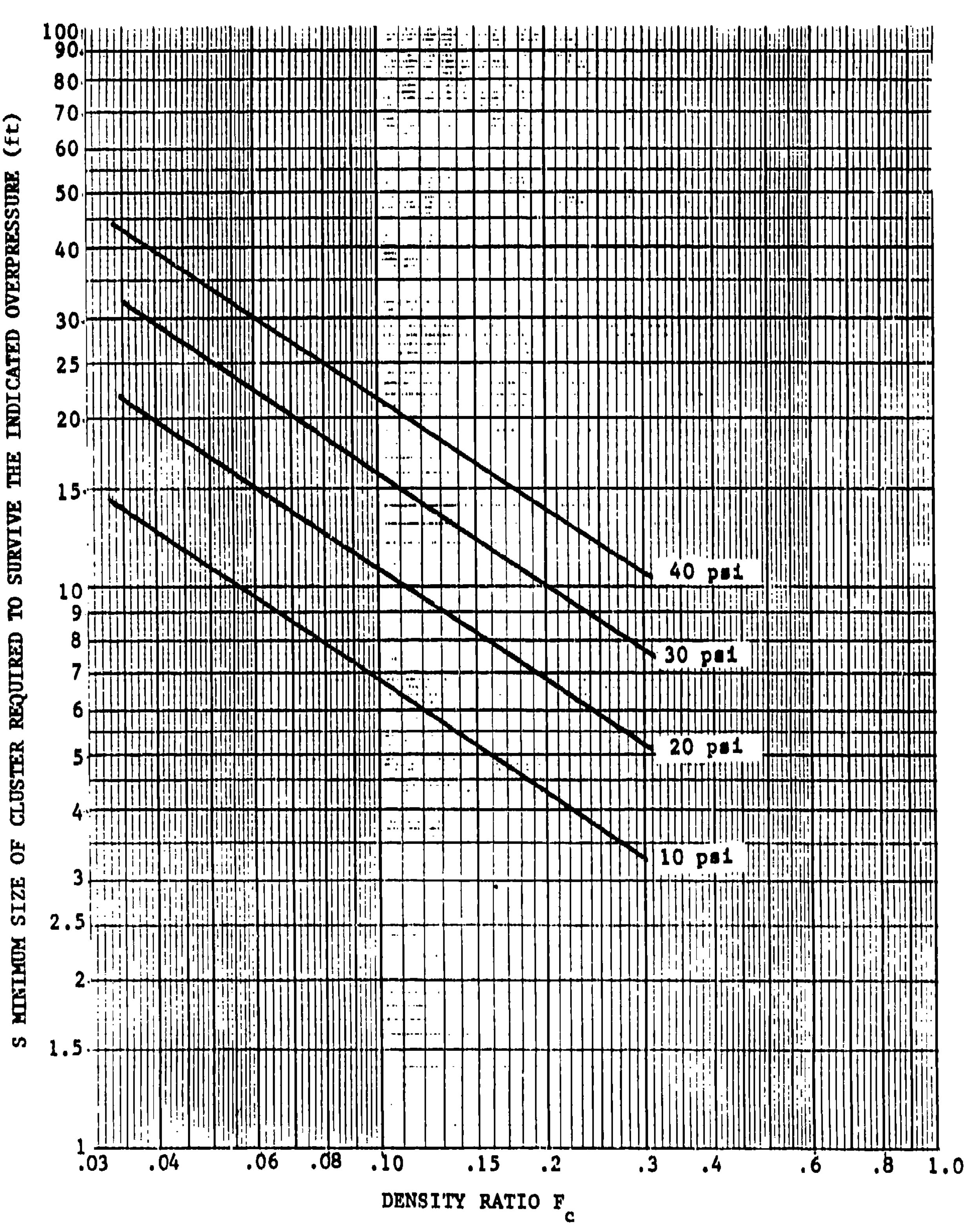


Fig. III-2. Survival Levels of Clustered Equipment for a 500 kt Weapon.

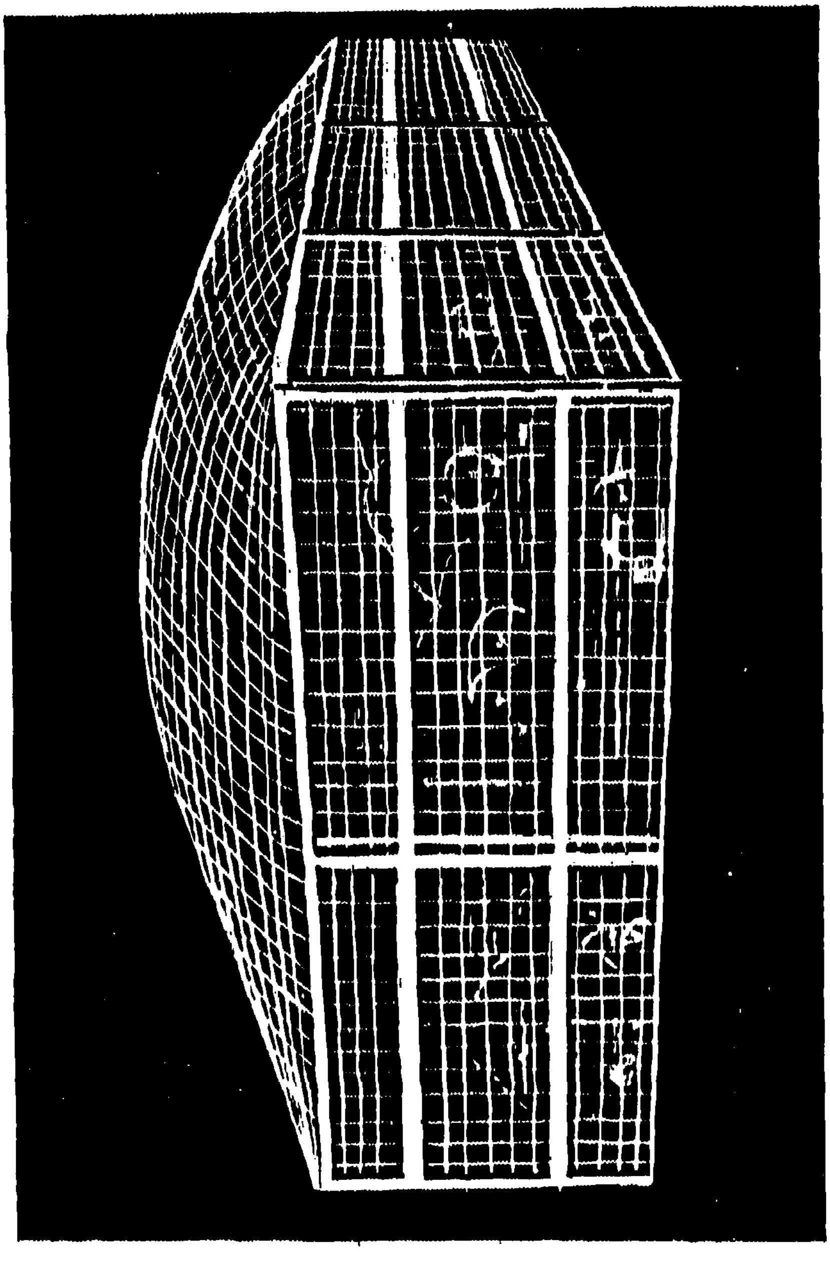


Fig. II-3. Channel and Chain Link Fencing Cluster Containment Package.

the channel and then a layer of sandbags stuffed inside, plus a layer of fencing over the top of the array, with a layer of sandbags over this, too, and another layer of fencing on top and welded to the channel to hold the sandbags in place, would provide reasonable missile protection and inhibit fire damage from any combustible solids in the area. Roughly, 600 to 700 sandbags and 12 cubic yards of soil would be needed. The resources to assemble the entire cluster (channels, fencing, sandbags, and sand or soil) would cost around $1,800.

To keep the apparent cost of these adjuncts to disaster preparedness down, they may be selected with the idea of putting them to alternative uses onsite. Obviously, the chain link fencing could be used as fencing. The soil (and/or sand) could be used for decorative purposes such as in raised planter boxes, and the channel (at about $3 per linear foot) might be used anywhere structural members are required -- as lighting standards, part of a building addition, or a storage rack. Thus, the actual standby cost for keeping these materials on hand in case of a national disaster could be reduced to something substantially less than their actual cost (perhaps to the equivalent of only three to five hundred dollars). Compared to the cost of the equipment that could be saved, this is very inexpensive disaster insurance. The important thing to note, however, is that such resources will not generally be available from suppliers at the time this kind of emergency situation arises (when everybody else wants them), so to ensure they are available, their acquisition would have to be made now or in the near future. The clustering option is the optimum hardening alternative to implement in terms of shortest time for executing, resources required, simplicity of keeping all necessary resources on hand (so implementation is independent of outside support), probability of enabling essential equipment to survive.

For the items not protected by the cluster (Table III-3), there are a number of options that can be considered. These items could be buried abovegrade, protected by packaging and anchoring, or evacuated on the two pickup trucks. The latter is the preferred choice. Rejected would be: trenching, because of the high water table; reorienting, because it would not provide sufficient protection; berming, because berming would take almost as much time and equipment as burying (and burying is the better choice, excepting where there is lots of equipment and little time - then berming, in conjunction with trenching, may be the optimum alternative).

Finally, nonessential items must not be left to create a problem (become missiles that impact the cluster). Therefore, such items should be left outside the cluster, but

in contact with it (so they may absorb other missile and impact damage), before they are blown away. In deciding which of the essential items to evacuate, rather than to be included in the cluster, it may prove beneficial to select items that will be of particular value in the host area. These would be things such as engine generator sets, welders, communications equipment. If a pressure sensitive item (i.e., collapsible under small external load) must be buried onsite, e.g., the oven, a sturdy slab would need to be placed over it to keep the overpressure load off it (burial ensures only that the wind won't blow it into something or something into it).

In the final analysis, Company X would plan to make the larger cluster, and to evacuate the oven, two TIG welders, and both the R & D and the production spot welders and band saws, in the two pickup trucks. All other options would take considerably more time (definitely at a premium) or resources that cannot be counted on. The plan selected involves resources that can all be in the control of the company - perhaps, one of the most critical elements in any survival plan. Table III-5 is the completed "COUNTERMEASURES/RESOURCES WORKSHEET" for Company X. It can serve as a blueprint for hardening in the event a warning is given.

TABLE III-5: COUNTERMEASURES/RESOURCES WORKSHEET, COMPANY "X"

COUNTERMEASURES/RESOURCES WORKSHEET

NUMBER	S	COUNTERMEASURE	LABOR REQUIREMENT TYPE	LABOR REQUIREMENT HOURS	MATERIAL REQUIREMENT TYPE	MATERIAL REQUIREMENT QUANTITY	EQUIPMENT REQUIREMENT TYPE	EQUIPMENT REQUIREMENT QUANTITY	TIME HOURS
1	35	24 X 26 CLUSTER	1 LABORER	2			BOLT CUTTERS	1	2
2	36	24 X 26 CLUSTER	2 LABORERS	1			FORKLIFT	1	1
3	35	24 X 26 CLUSTER	2 WELDERS	2	6" x 15.3 LB CHANNEL 4" x 7.25 LB CHANNEL	12 EA-26 FT 10 EA-2 FT	WELDER	2	2
4	35	24 x 26 CLUSTER	2 WELDERS	2	6 FT CHAIN LINK FENCE	220 FT	WELDER	2	2
5	35	24 x 26 CLUSTER	4 LABORERS[a]	3	SANDBAGS	700	SHOVELS	4	3
6	35	24 x 26 CLUSTER	2 LABORERS	4	SAND OR SOIL	12 YDS	PICKUP #1 PRIVATE AUTOS	1 2	2 1
7[b]	35	4 EA IN CLUSTER 2 EA EVACUATE					FORKLIFT PICKUP #1	1 1	.25
8	SAFE	EVACUATE	3 LABORERS	.25	FILLED 5 GAL GAS CANS	6	PRIVATE AUTOS	2	
9[b]	SAFE	EVACUATE	4 LABORERS	.25	STRAPS OR WEBBING	100 FT	FORKLIFT PICKUP #1	1 1	.25

a. Sandbag filling must start when bolt cutting starts.

b. Two TIG Welders used to make cluster to be loaded on Pickup #1 together with items 9 and 10 and their R & D counterparts. Forklift is required for loading pickups, and is to be in the cluster also, so that all these items must be loaded on Pickup #1 before final welding of channel.

NOTE: Last minute items and tools to be evacuated to private auto. Caravan of two pickups plus autos from site to Host Area.

TABLE III-5: COUNTERMEASURES/RESOURCES WORKSHEET, COMPANY "X" (contd)

COUNTERMEASURES/RESOURCES WORKSHEET

NUMBER	S	COUNTERMEASURE	LABOR REQUIREMENT TYPE	LABOR REQUIREMENT HOURS	MATERIAL REQUIREMENT TYPE	MATERIAL REQUIREMENT QUANTITY	EQUIPMENT REQUIREMENT TYPE	EQUIPMENT REQUIREMENT QUANTITY	TIME HOURS
10 [b]	SAFE	EVACUATE	4 LABORERS	.25	ROPE	50 FT.	FORKLIFT PICKUP # 1	1 1	.25
11	35	24 X 26 CLUSTER	COVERED ON PAGE 1						
12	35	24 X 26 CLUSTER	COVERED ON PAGE 1						
13	SAFE	EVACUATE	4 LABORERS	.5	STRAPS OR WEBBING	100 FT	FORKLIFT PICKUP # 2	1 1	2 [c]
14	35	24 X 26 CLUSTER	COVERED ON PAGE 1						
15	35	24 X 26 CLUSTER	COVERED ON PAGE 1						
16	35	24 X 26 CLUSTER	COVERED ON PAGE 1						

b. Two TIG Welders used to make cluster to be loaded on Pickup #1 together with items 9 and 10 and their R & D counterparts. Forklift is required for loading pickups, and is to be in the cluster also, so that all these items must be loaded on Pickup #1 before final welding of channel.

c. No longer available after loading.

NOTE: Last minute items and tools to be evacuated to private auto. Caravan of two pickups plus autos from site to Host Area.

CASE II

COMPANY "Y" A SMALL INDUSTRY

FACILITY DESCRIPTION

Location and Local Hazards

This firm is located on the east side of the San Francisco Bay opposite to Company X and somewhat north of it. The major hazards for this location are earthquakes, nuclear attack, hazardous materials, and fire. The latter two hazards are onsite threats, while the earthquake threat is from proximity to the Hayward Fault. The nuclear attack threat at this location is 13 psi (according to TR-82).

Product and Markets

The company is engaged in manufacturing specialty paint products for private industry and the government. Runs are generally small, not exceeding 200 gallon lots, and are mixed to match samples provided or a product previously developed for a customer. Testing the spectral match of the completed run after application to a sample and specifying the hazards of the final product are the two major requirements that border on high technology, otherwise operations are extremely simple. Grinding, mixing, blending, and packaging are the principal activities.

Utilities

For production operations, utility requirements are:

- Electricity: 220/440 volt, 1,000 amp service
- Gas: Comfort and water heating only
- Water: Minimal for production, large for fire safety

The largest single demand for power is 200 amps which is drawn in starting up the motor on the sandmill (a heavy duty pigment grinder).

Personnel Support

About 15 full-time employees are required to operate the facility in a normal environment. Half are involved in production, the rest are in quality control and administrative positions. There are two highly qualified chemists, one additional chemist, and the remainder are experienced employees, but most without highly technical educations.

Production Process

The paint products are all specialty items. The larger quantities are manufactured from basic pigments, resins, thinners, and other additives (e.g., deglossers), while smaller quantities (a gallon or two) are made up from basic white, which is then tinted. This latter process is only for small runs because it is considerably more expensive than the former.

The larger scale process essentially involves grinding pigments into resins; blending these to get the colors desired; then [illegible] this with appropriate quantities of thinner to obtain desired drying times and conditions; testing the product in the quality control lab for reflectivity and color; adjusting the batch accordingly; determining the final chemical makeup; packaging the product in cans (5 gallon or smaller); labeling; and making up the Material Safety Data Sheet that corresponds to the packaged product. Quality control testing consists of applying some of the finished product to a small piece of material with a surface similar to that for which the product is intended, drying it, and testing it spectrally for quality of match. Production equipment is limited principally to forklifts for materials handling, sandmills for grinding pigments into the resins, agitators to blend the appropriate amount of thinner, dispensers for the final blending and transfer to completed product storage, spray equipment for testing samples, small ovens for drying the samples for quality control tests, and scales.

Priorities

There are no items of equipment that are critical. Basically, all operations could be done by hand without any electric power by just using simple mechanical devices and appropriate mechanical advantage. Rates would be considerably slower, to be sure, but all that would be required are some tanks in which to do the mixing, some paddles, and motive power of any sort could be used to turn the paddles. Items required are common and readily fabricated from scrap.

Special Problem

Because substitutes may be easily found for all Company Y's equipment, this facility could be abandoned and key personnel moved to a safe area to establish a jury rigged plant in which to produce paint (given the necessary ingredients). There is a serious problem with this particular decision, however, in case of a nuclear attack; i.e., what to do about the considerable quantity (thousands of gallons) of hazardous materials onsite. About fifteen hundred 55-gallon drums of flammable, combustible,

and explosive materials at this facility pose a significant threat to neighboring industries that attempt to protect their equipment in this industrial park. It is unlikely these quantities of hazardous materials could be removed because there are enough drums to fill five or six trailers, and a like number of tractors would be required to move them. It would be important to the survival of adjacent facilities that something be done to reduce this threat.

VULNERABILITY/SURVIVAL ANALYSIS AND COUNTERMEASURE SELECTION

Table III-6 summarizes data for Company Y on the "ESSENTIAL EQUIPMENT INVENTORY WORKSHEET."

Table III-7 is the "ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET" for processing the Table III-6 data to arrive at the survivability without protection rating.

ASSESSMENT OF ALTERNATIVE METHODS FOR HARDENING TO TARGET OVERPRESSURE

Resources immediately available onsite at this facility are limited. All the raw materials (drums, 60 to 100 lb sacks of solids, empty paint cans for packaging) are brought in and the finished materials shipped out on common carriers. The company has three forklifts, however, with 4,000-lb capacity and there are 10 acres of raw land adjacent to it (the company's site is completely paved with either concrete or asphalt so spills will not sink into and contaminate soil), and there is a 6-foot high chain link fence on three sides of the property (so the total available linear feet of this material is 800 feet).

Running quickly over the hardening alternatives to see which might be practical for protecting critical equipment: protective housekeeping is the biggest problem at this site because of the fire hazard from the hazardous materials (more on this problem later); clustering would provide protection to about 12 psi (with an F = 0.032 and S = 16 feet) so this falls short; neither reorienting nor isolating would increase survivability enough alone, but together would just about make 13 psi (however, isolation would require use of the majority of the property adjacent and this is a very

TABLE III-6: ESSENTIAL EQUIPMENT INVENTORY WORKSHEET, COMPANY "Y"

ESSENTIAL EQUIPMENT INVENTORY WORKSHEET (E+RR = 5 OR LESS)

NUMBER	E+RR	EQUIPMENT NAME & DESCRIPTION	QTY	WEIGHT (W) in lbs	HEIGHT (H) in ft	LENGTH* (L) in ft	DEPTH (D) in ft	REMARK
1	5	SAND MILL	6	1,200	6.5	3.5	2.0	BOLTED TO FLOOR
2	5	DISPENSERS	6	800	6.0	3.5	2.5	BOLTED TO FLOOR
3	5	AGITATORS	6	900	6.3	3.2	2.2	BOLTED TO FLOOR
4	5	FORKLIFT	2	5,400	6.7	7.0	4.1	MOBILE
5	5	FORKLIFT	1	3,600	6.5	6.2	3.2	MOBILE
6	**	HAZARDOUS MATERIALS	1,500	400	2.6	2.0	2.0	FREE STANDING

*Use Longest Horizontal Dimension

** A high priority because of the considerable risk posed to hardened equipment in the area.

TABLE III-7: ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET, COMPANY "Y"

ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET

NUMBER	EXPOSED AREA IN SQ FT	WEIGHT/UNIT AREA IN LBS/SQ FT (W/A)	DENSITY FACTOR (F) = 0.002W/DHL	SURVIVABILITY SEE TABLE*
1	22.9	55	0.055	1
2	21	38	0.030	1
3	20	46	0.019	1
4	47	115	0.056	3
5	40	89	0.066	2
6	5	60	0.060	2

*Where W/A falls between listed values, use S for the smaller listing

VULNERABILITY/SURVIVABILITY TABLE

W/A	S
30	1
60	2
110	3
160	4
220	5
280	6
360	7
440	8
530	9
630	10
700	11
900	12
1100	13
1300	14
1500	15

poor use of such a resource even if it belonged to Company Y - hence, this option is not considered viable); evacuation would require a large truck (not available onsite); packaging and anchoring is a poor choice because of the fire hazard with all the hazardous materials around, unless these are dealt with; trenching is possible, but would not protect the equipment from the fire hazard; berming would require moving as much earth as trenching and would also not provide protection from the fire hazard; burial belowgrade is viable, however, and will protect the equipment from the fire hazard - about 20 yards of soil in the adjacent raw land would have to be moved by shovels, the equipment placed in the excavation and the soil replaced on top; abovegrade burial directly onsite is also a possibility using the inventory of bagged solids (this would have the added benefit that it does not require shovels). In summary, the last two alternatives are the most viable options and the choice is between these two.

Table III-8 presents the COUNTERMEASURES/RESOURCES WORKSHEET for Company Y. Because of the significant protective housekeeping problem with the hazardous materials and the risk these pose to the company and adjacent facilities alike, these materials must be included as essential to harden. The best option for hardening drums of hazardous materials in quantity is by clustering them. Full drums of water have an F = 0.11. With solvent in them they run about F = 0.08, so that an array size of S = 11 feet would be adequate for the expected overpressure at Company Y. To provide a cushion for judgmental and targeting errors, an S = 13 would withstand slightly over 20 psi and provide a convenient array roughly 7 drums by 7 drums. As there are around 1500 drums, thirty such arrays would have to be made and each of them would require material to hold them as a unit. Chain link fencing is the major resource onsite for this but there is only enough onsite for 15 or 16 such arrays, so the best approach is to make larger arrays. There should be at least four or five of them anyway for the following reasons. To start, some drums must be kept separated onsite because of incompatibilities in the contents (they would react if spilled and mixed). Also, there are some that are only partially full. These will distort under load (unless they can be combined to make full drums) so should be in a separate array somewhat removed from the others. Finally, there are two types of drum, one with the ends an integral part of the drum and one with a removable lid. These two types should not be mixed in the same cluster. Separating the drums at Company Y according to these principles would result in six arrays. The smallest would be about 10 feet on a side and would require 40 feet of chain link fencing to contain. The largest would be about 50 feet on a side and require 200 feet of chain link fence to contain.

TABLE III-8: COUNTERMEASURES/RESOURCES WORKSHEET, COMPANY "Y"

COUNTERMEASURES/RESOURCES WORKSHEET

NUMBER	S	COUNTERMEASURE	LABOR REQUIREMENT TYPE	LABOR REQUIREMENT HOURS	MATERIAL REQUIREMENT TYPE	MATERIAL REQUIREMENT QUANTITY	EQUIPMENT REQUIREMENT TYPE	EQUIPMENT REQUIREMENT QUANTITY	TIME HOURS
1	40	BURY	4 LABORERS 3 OPERATORS	6 1	LOCAL SOIL	20 YDS	SHOVELS FORKLIFTS	4 EA 3 EA	6 3
2	40	BURY	COVERED UNDER ITEM 1		COVERED UNDER ITEM 1		COVERED UNDER ITEM 1		3
3	40	BURY	COVERED UNDER ITEM 1		COVERED UNDER ITEM 1		COVERED UNDER ITEM 1		
4	15	CLUSTER & BERM	4 LABORERS	6	CHAIN LINK FENCE LOCAL SOIL	38 FT 20 YDS	SHOVELS	4 EA	3
5	15	CLUSTER & BERM	COVERED UNDER ITEM 4		COVERED UNDER ITEM 4		COVERED UNDER ITEM 4		
6	30	CLUSTER	3 OPERATORS 4 LABORERS	5 5	CHAIN LINK FENCE SOLIDS (BAGGED)	800 FT 300 BAGS	FORKLIFTS BOLT CUTTERS	3 EA 1 EA	5

For the arrays with drums of volatile solvents (highly flammable, and even explosive under some conditions), it would also be desirable to have a soil berm around the outside to protect against missiles that might rupture some drums and initiate fires (exploding drums could blow the array apart, rupture more durms, start more fires, and cause an additional hazard to neighboring facilities). To place a berm around the outside of these drums, the solid materials (in sacks) could be placed between the drums and the chain link fence (so not so many sacks would be required). If heavy earthmoving equipment were available it would take no more than two hours to place a berm around all the arrays. (If there were other facilities in the area with hazardous materials, it would behoove them and their immediate neighbors to pool efforts to get all hazardous materials drums in the vicinity protected - in this instance, no survey was made to assess the situation but it is the kind of community planning that should be encouraged.) Because the dry solids in sacks are to be used around the solvent drum arrays, the option to bury the equipment items belowgrade was selected over the abovegrade burial.

The final plan at Company Y does not involve use of any materials or equipment excepting what can absolutely be counted on; i.e., items that are available onsite at the time of the emergency. This requires advance purchase of two additional shovels and some bolt cutters (to cut the chain link fencing, which would speed the process of containing the arrays). To tighten the arrays once the chain link fence is around them, two by fours from wood shelving would be jammed between drums and fencing.

CASE III

COMPANY "Z" AN EMERGENCY SERVICES AGENCY

FACILITY DESCRIPTION

Location and Local Hazards

This agency, which serves all of San Mateo County, is located on the peninsula adjacent to the San Francisco Bay in one of the county's major cities. The principal hazards that could threaten this facility are earthquake and nuclear attack. The earthquake threat is from proximity to the San Andreas Fault, the nuclear attack threat according to TR-82 will probably exceed 16 psi (it lies within a grid square for which the overpressure at the center is expected to be 16 psi, but four of the eight adjacent grid squares are indicated as having overpressures at the center that exceed 20 psi; i.e., indicating there is a target somewhere within each such box).

Product and Markets

The agency is an emergency services organization whose principal product is coordination of community resources to mitigate emergency and disaster situations in San Mateo County. The single capability most critical to this task is an operational communications link. (Communications, coordination, and mutual aid agreements with adjacent communities are also part and parcel of the agency's function.) To support overall mitigation activities, the agency maintains a yard stocked with a variety of public works equipment for emergency use (generators, vans, water tankers, graders, bulldozers); it also keeps tabs on the locations of many more assets of a similar nature in other yards that it might call for in an emergency.

Utilities

As an emergency services agency, this organization has portable systems to use for its mission when regular utility service may be knocked out.

Personnel Support

The agency has six full-time professionals, one technical professional to maintain yard equipment, and three support personnel.

Production Process

As emergency services is the major product, the agency's main task is communications, particularly where it involves tieing suppliers of resources and emergency response teams into coordinated activities in support of those who suffer serious effects from an emergency or disaster event. This task is facilitated by numerous fixed equipment: radio consoles (in the County Communications Center), microwave dishes, repeaters, antennas; and mobile equipment consisting of hand-held radios and a Communications Van/Command Post. Direct support equipment includes water purification units, portable and mobile generators, water tankers, and earth-moving equipment.

Priorities

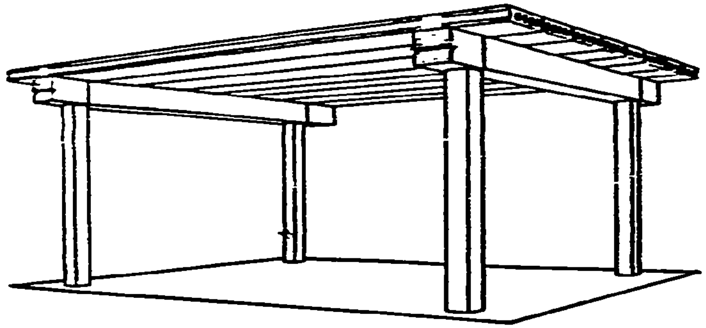
The agency's main priority is to provide emergency services in support of life safety and property protection in the community.

VULNERABILITY/SURVIVABILITY ASSESSMENT

In event of the threat of a nuclear attack, excepting for the fixed communications system in the main center, all the equipment is mobile and would be moved rapidly to the Host area. As continuity of function at the agency is especially critical, little time could be devoted to hardening the fixed communications equipment. Current plans call for abandoning the fixed equipment and operating from the mobile units. As evacuation is the principal hardening mode, it is presumed such equipment will be rated as safe, it being no longer at risk.

The agency is, however, located in the basement of a structure with characteristics that can be found among the belowgrade hardenable facilities illustrated in Part V of this report. A brief assessment using Figure III-4 (light and medium structures, from Part V, Figure V-18) indicates that the basement area might be hardened to 19 psi, using 12-inch timbers for post and beam shoring. This level of overpressure survivability might be adequate to enable the fixed communications facility to survive, as PE = 16 psi according to TR-82. The entire basement would have to be shored, however, for this hardening method to be effective. The agency takes up less than 15% of the basement space so that the effort would not be commensurate with the anticipated benefit.

PRECAST PRESTRESSED HOLLOW-CORE SLAB FLOOR

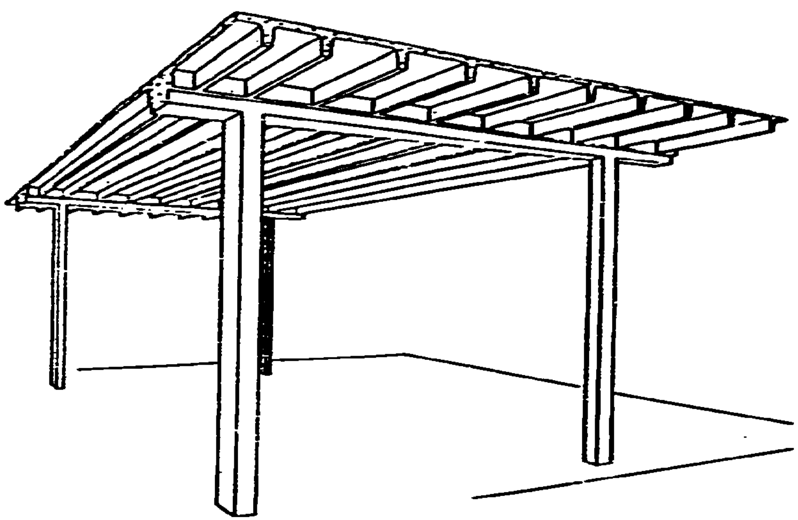


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	17
MEDIUM	3	20

SHORING TYPE – P & B

A

REINFORCED CONCRETE ONE-WAY JOIST FLOOR



DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	19

SHORING TYPE – P & B

B

III-4 Concrete Floor Systems.

PART IV

CONCLUSIONS AND RECOMMENDATIONS

PART IV

CONCLUSIONS AND RECOMMENDATIONS

Based on the limited assessment of the procedure to date, it appears to be considerably easier to apply than prior methods. Time-consuming steps that do not contribute directly to a method to protect equipment have been greatly reduced and are now far less than for any other procedure in print. A program would be necessary to assess industry's response, however, as such an assessment was not within the scope of this program.

Recommendations are in two areas, one dealing with technical factors and reliability of vulnerability/survivability assessments, and the other dealing with applications practicability.

The major recommendation to come out of the vulnerability/survivability assessment study is that further work should be conducted in several areas related to determining the vulnerability of industrial equipment to nuclear effects and to providing protection from these effects. The specific areas listed in order of priority are given below:

1. Protective capabilities of clusters

2. Response of equipment to head-on impact

3. Response of equipment to fragment impact

4. Motions of equipment under blast loading

For all of the above areas, it is recommended that the starting point for further work be an experimental test program. This is because it is believed that the theoretical analyses conducted to date have gone as far as it is profitable to go without further verification and guidance from experiments.

Details of the recommended experimental program including required facilities and estimated costs are given in Part II, Section 5, Recommended Additional Testing.

In the area of applications practicability, it is recommended that further evaluation by industrial planners be made of the procedures developed for determining equipment survivability and for developing countermeasure plans. These procedures are self-contained in Part V of the report.

Several case histories are covered in Part III of the report, but previous experience has found a wide range of response to this subject in terms of both interest and capability to grasp the essentials, so that a thorough evaluation of the procedures is likely to require more than two or three opinions.

An additional recommendation is that further industry application be facilitated by some kind of exposure, nationwide, to multi-hazard planning and concepts. This might be easier to accomplish through public television, thus providing a national consciousoness and common base for the evolution of a practical, effective methodology.

Finally, it is recommended that all such efforts be coordinated and directed towards the evolution of standard industrial training programs.

PART V

MANUAL FOR PROTECTION OF ESSENTIAL INDUSTRY EQUIPMENT FROM NUCLEAR WEAPONS EFFECTS

PART V

Section 1
PROCEDURES FOR PROTECTION OF ESSENTIAL INDUSTRY EQUIPMENT

The planning process for protection of industrial and business equipment involves four steps: Step 1 - Identification of the threat; Step 2 - Inventory of essential equipment that will need to be protected; Step 3 - Analysis of that equipment to determine its vulnerability to the various nuclear weapon effects, and Step 4 - Selecting appropriate countermeasures to protect the selected items of essential equipment. These steps are outlined in Figure V-1.

Step 1: THREAT IDENTIFICATION

Because it is expected that most industrial/business planners are not familiar with nuclear weapon effects we will start with a brief description. The most damaging effects of explosions, in general, result from a very rapid release of large amounts of energy within a limited space. This applies to conventional high explosives, such as TNT, and to nuclear explosions, although the energy is released in different ways. This sudden release of energy causes a considerable increase of temperature and pressure as the materials present are converted into hot, compressed gases. The resultant high-temperature, compressed gases expand rapidly, creating a pressure or "shock wave" in the surrounding medium. In air, this shock wave is generally referred to as a "blast wave" because it resembles and is accompanied by a very sudden, strong wind. In the ground, however, the term "ground shock" is used, and the effect is like that of a sudden impact.*

A nuclear blast is similar to that from conventional explosives in that the destructive actions are primarily due to blast and shock. There are, however, several basic differences between high-explosive and nuclear weapons. First, the latter can be many thousands or millions times larger. Second, for the release of a

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*Much of this description was taken from an excellent reference, **The Effects of Nuclear Weapons,** compiled and edited by S. Glasstone and P.J. Dolan. This book is available for sale from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

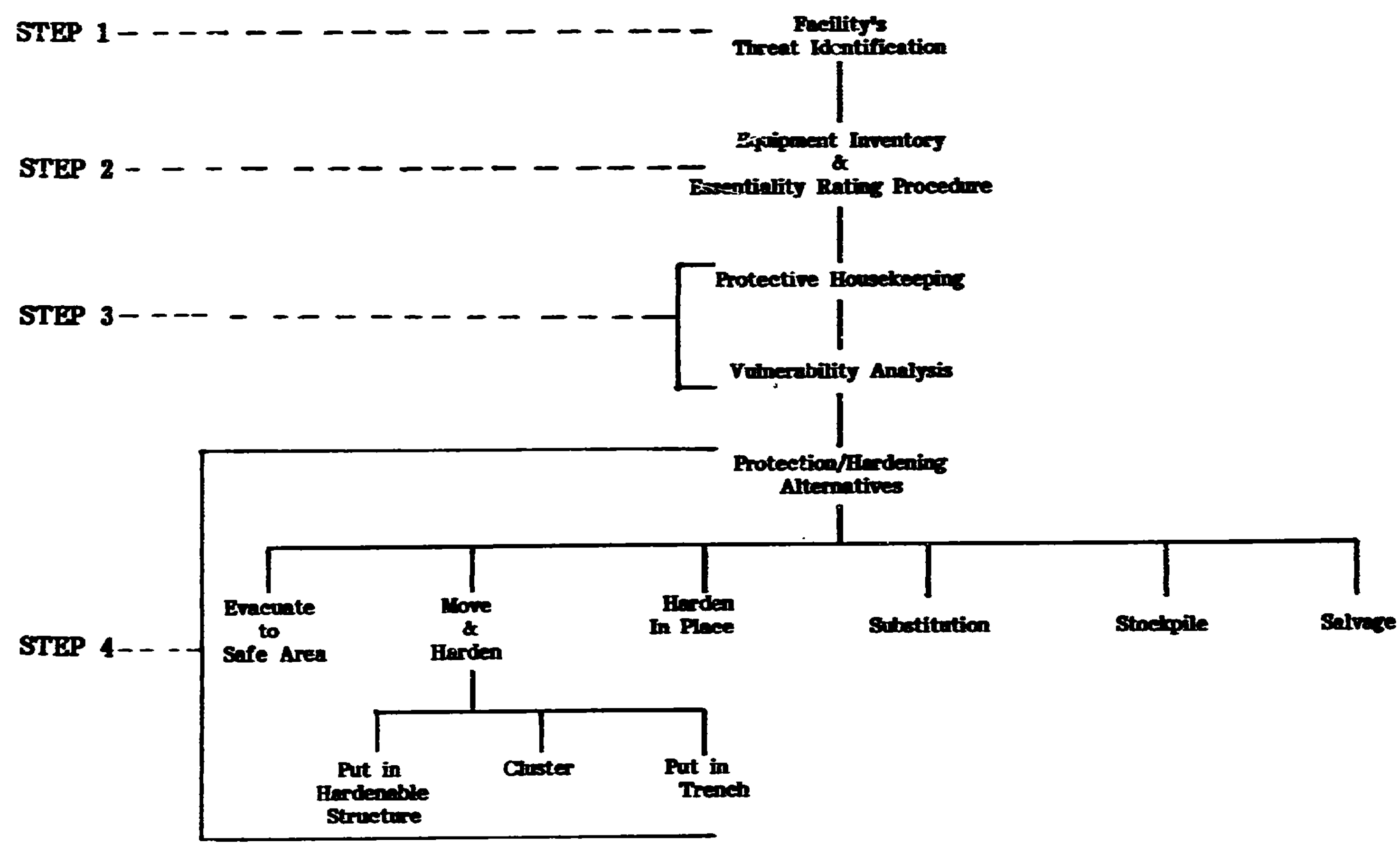


Fig. V-1. Steps to Identify and Protect Critical Equipment

given amount of energy, the mass of a nuclear explosive would be much less than a conventional explosive (theoretically 2 ounces of fissionable material is the energy equivalent of 1 kiloton, 1 thousand tons, of TNT). Third, the temperatures reached in a nuclear explosion are much higher than in a conventional explosion, and a fairly large proportion, approximately 50%, of the energy of a nuclear explosion is emitted in the form of light and heat, generally referred to as "thermal radiation." Fourth, the nuclear explosion is accompanied by highly penetrating and harmful invisible rays, called "initial nuclear radiation." If a nuclear weapon is detonated at a high altitude the initial radiation, as well as the residual radiation (discussed below), will interact with the constituents of the atmosphere and create a phenomenon known as "electromagnetic pulse," or EMP, which is capable of causing damage to unprotected electrical and electronic equipment over an extensive area. Finally, the substances remaining after a nuclear explosion are radioactive, emitting radiation over an extended period of time. If a nuclear weapon is detonated on or near the ground surface, large quantities of dust particles can become radioactive and can travel long distances, returning to the ground as "fallout," which produces extensive radiation fields that can be lethal for hours to days.

How each of these weapons effects, singly or in combination, can be threats either to life safety or to the facility and plant equipment is briefly discussed below.

Blast Wave

The blast wave is probably the most serious threat of concern for facility and equipment protection. Of course, without special structures in place, or a combination of evacuation and sheltering, it would be a serious threat for life safety too. The magnitude, and thus damage potential, of a blast wave depends on the size of the source and the distance from it. The most current targeting scenarios are based on multiple warhead delivery systems, which would indicate that the weapons of concern would range in size from 100 to 500 kilotons (kt). For structures and equipment, gross estimates of damage as a function of overpressure are shown in Table V-1.

Ground Shock

Ground shock damage to industrial equipment will be a problem only in special cases, i.e., in hardened facilities subjected to overpressures above 20 to 30 psi; it is a life-threatening (actually injury producing) problem only in shelters subjected to overpressures above 40 to 45 psi. It is of concern, however, in the design of equipment for essential worker shelters.

TABLE V-1
DAMAGE RANGES FOR 500 KT NUCLEAR WEAPON

Peak Wind Velocity (mph)	Positive Phase Duration (sec)	Peak Dynamic Pressure (psi)	Peak Over-Pressure (psi)	Range from Ground Zero (MILES)	
					Light damage to window frames and doors, moderate plaster damage out to about 15 miles; glass breakage possible out to 30 miles.
				7	
44	3.4	0.036	1.2		
51	3.4	0.049	1.4	6	Fine kindling fuels ignited.
60	3.4	0.072	1.7		
				5	
					Smokestacks: slight damage. Roofs damaged.
72	3.1	0.11	2.1		
					Wood-frame buildings: moderate damage.
89	2.9	0.16	2.6	4	Radio and TV transmitting towers: moderate damage.
					Wood-frame buildings: severe damage. Telephone & power lines: limit of significant damage.
117	2.7	0.28	3.5		
				3	Wall-bearing, brick buildings moderate damage.
					Wall-bearing, brick buildings severe damage.
177	2.5	0.60	5.5		Light steel-frame, industrial buildings: moderate damage.
					Light steel-frame, industrial buildings: severe damage. Multistory, wall-bearing buildings (monumental type): moderate damage.
276	2.1	1.9	9.4	2	Multistory, wall-bearing buildings (monumental type): severe damage.
					Highway and RR truss bridges: moderate damage. Multistory, steel-frame building (office type): severe damage.
					Transportation vehicles: moderate damage.
464	1.8	7	18.0		Multistory, reinforced-concrete frame buildings (office type): severe damage.
				1	All aboveground structures destroyed out to here.
890	0.9	30	45	0.7	Belowground structures hardened to 50 psi required for survival
				0	Ground zero for 500 kt air burst

Source: Adapted from **The Effects of Nuclear Weapons**, 1962 edition.
(Note the distances given are the average for Zero and Optimum Burst Heights)

Thermal Pulse

The primary thermal pulse should not be a problem to sheltered personnel, but it is of serious concern to protection of industrial facilities and equipment. The primary problem with this thermal pulse will be the igniting of numerous small fires, which, if they spread, can cause more damage and destruction than any of the other weapons effects and can extend into regions where blast damage is not a problem. To complicate the problem even further, secondary fires need to be considered. These are fires that result from blast damage to facilities and equipment and could be started by electrical shorts, spills of flammable liquids, etc.

Initial Nuclear Radiation

Initial radiation is of concern for life safety and must be taken into account in the design of key worker shelters. It is also of concern with regard to damage to industrial equipment in that it can cause temporary or permanent damage to various components of electronic equipment, such as transistors, capacitors, resistors, certain types of cables, and to a lesser extent batteries. However, as damage to electronic equipment from initial radiation is likely to occur only at overpressures above 10 psi, while blast damage to this equipment will occur below 10 psi (and encompass an area three to four times larger than that subjected to 10 psi or more) the blast damage is likely to be of more serious concern. Also, almost all of the blast protection methods recommended in the industrial equipment hardening guidance will furnish adequate protection from initial radiation as well.

EMP

EMP, or electromagnetic pulse, is not a direct threat to life safety; it is a significant threat to the survival of electronic and electrical equipment. It is also the most widespread of the nuclear weapons hazards, since damage can occur over great distances. In order for damage to occur to electronic or electrical systems it would be necessary for the energy to be collected over a considerable area by means of a suitable collector. Unfortunately, industry has many suitable collectors including long runs of cable or conduit, overhead power and telephone lines, antennas of all sorts, long runs of electrical wiring or conduit in buildings, metal buildings, metal fences and water pipes, and railroad tracks. The primary protection methods are to disconnect nonoperating equipment from these possible collection sources or to provide special shields and grounds designed to decouple operating equipment.

Fallout

Fallout is a serious life safety hazard. It requires shelters for both the key workers and the evacuated population with the first of these being the more demanding. For the most part, suitable blast shelters for key workers will be sufficiently adequate structurally for modification to provide adequate radiation shielding. Protection from fallout has been considered extensively in other research efforts and will not be considered here. For information on the subject please refer to the **DCPA Attack Environment Manual, CPG 2-1A6.**

Summary

A summary of each of these nuclear weapon effects is presented in Figure V-2. The weapon size used was 500 kt. In this figure it was assumed that equipment might begin to be damaged by heavy items on the building's roof (e.g., air conditioners) when the roof collapses (at approximately 2 psi). To indicate the effect of proper planning, as suggested in this guide, see Figure V-3. Here, the assumptions are that industrial equipment is protected to 12 psi (a fairly easily obtainable goal), key workers are supplied with sealed shelters that furnish protection to 50 psi, and the various protection measures suggested in the guide for fire prevention and other activities have been implemented. It will be noted that some of the effects, particularly fire, are shown with dotted lines. This indicates uncertainty in the available data and shows where further research is needed.

To assess the vulnerability of a particular site to nuclear attack requires an assumption of an attack. Current civil defense planning has been based on an analysis by the Federal Emergency Management Agency and the Defense Department of the potential hazards from a nuclear attack in areas considered relatively more likely to experience the direct effects (blast, fire, and initial radiation). The results of this analysis are presented in a publication entitled "High Risk Areas for Civil Defense Preparedness Nuclear Defense Planning Purposes" TR-82. This publication is currently being revised to reflect changes in delivery systems (multiple warheads, thus, smaller weapons than those used in the original document). The only unclassified information available on the subject indicates the priorities of target locations in descending order will be: nuclear weapon delivery systems and their associated command, control, and communications; political-administrative centers; military installations; military-industrial manufacturing plants (plus selected firms performing critical research and development for the Department of Defense); electric power generating plants; chemical manufacturing plants; critical

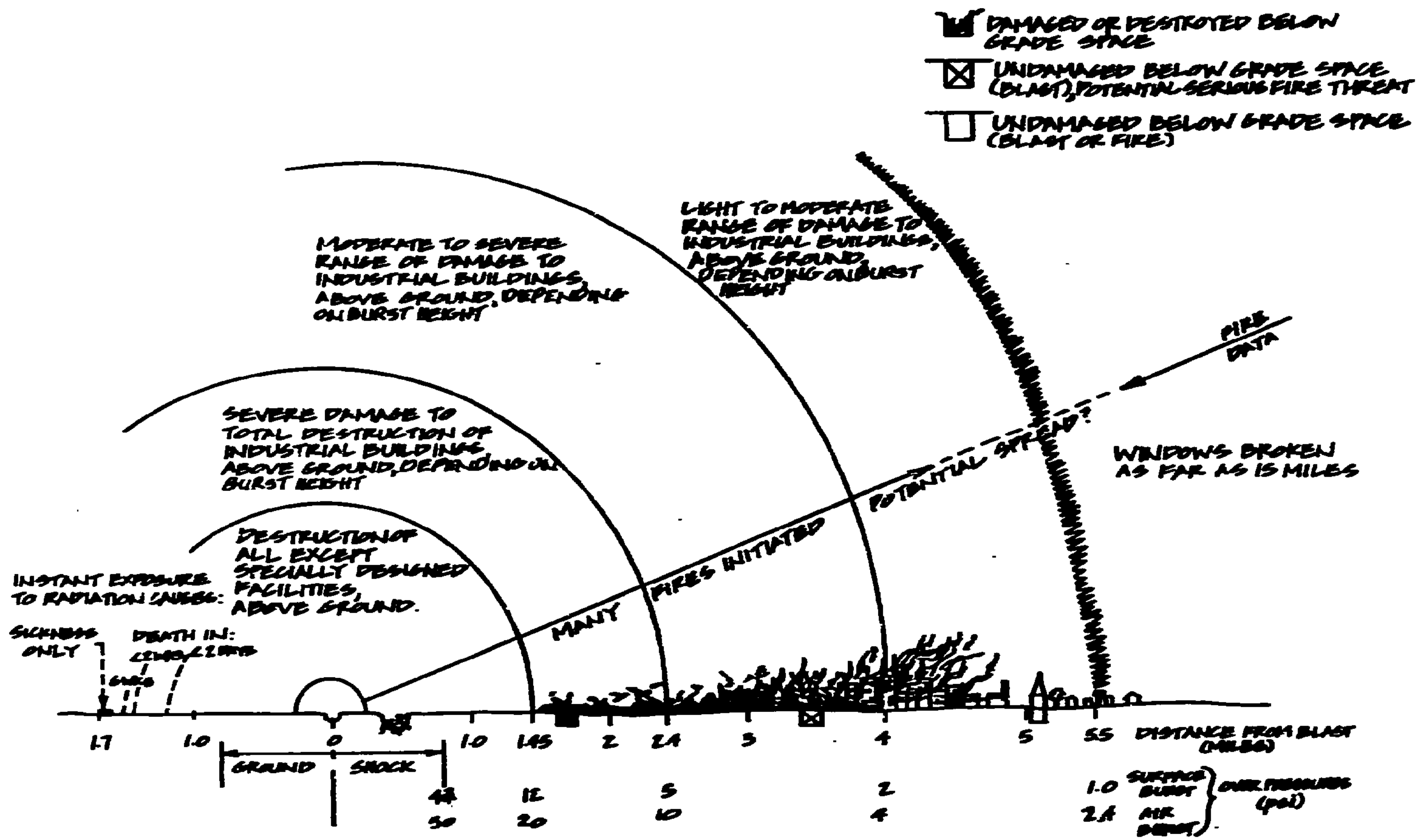


Fig. V-2. Damage Effects in the Risk Area Without Protection (500 kt Blast on Surface or in Air).

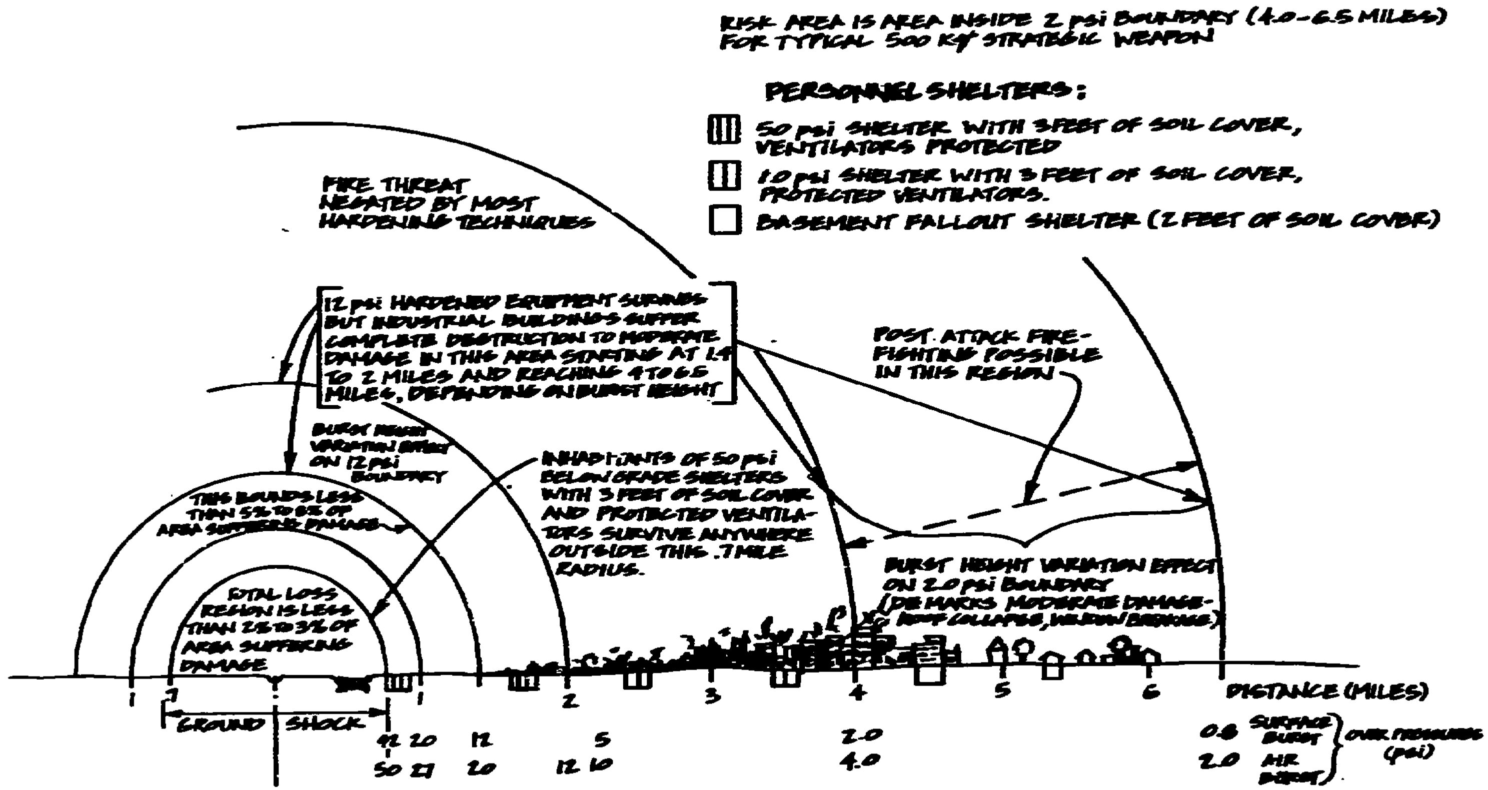


Fig. V-3. Survival Benefits in the Risk Area With Shelters and Equipment Hardening (500 kt Blast on Surface or in Air).

transporation facilities, especially ports used for embarkation of military forces and equipment; and refineries. Assignments were developed considering U.S. active defenses, vulnerability, and time sensitivity of targets, etc., with the objective of maximizing targets destroyed and minimizing weapons expended.

It is realized that the above discussion poses problems for the industrial planner in assessing the vulnerability of a particular facility. Until a new risk map is prepared for each area, an industrial planner should assume that, if the facility is within 8 miles of a counterforce target (e.g., a missile or missile control site) and within 5 miles of one of the target designations noted above, he will be in a risk area subject to pressures in excess of 2 pounds per square inch and thus will need to consider the vulnerability and protection aspects that follow.

Step 2: INVENTORY OF ESSENTIAL EQUIPMENT

Step 2 in the process of developing an industrial protection plan is selecting the various items of equipment that are essential. This requires a different mind set than is normally used by industrial managers. The normal response to the question - What in your facility is essential? - brings a response that typically goes like this: "Everything; otherwise, we would not have it." When you change the question to - You have 72 hours before a major disaster will strike your facility, you won't have time to protect everything, what are the few items of equipment that you would like to save so that you could resume production after the disaster? - some interesting responses are obtained.

For example, a paint manufacturer responded that nothing was essential, he could make paint with a 55-gallon drum and a 2x4 (if he had the raw material). Further analysis brought out some items of equipment that he decided were essential and should be protected, but the end result was, the items selected were far fewer than were in evidence in the plant as currently operated. Similar responses have been obtained in other plants, indicating that after careful thought a list of essential equipment, far less than was normally used, was developed.

Before taking up the subject of determining the essential equipment in a process, it might be useful to discuss a practical methodology for arriving at those elements of an industrial facility that are essential to output. The quickest route is

to begin with an elimination process. In the first step, general facility operations are broken down by types. Among these different types of operations will be some that are quickly recognizable as not critical during a crisis period (because of changed priorities), i.e., there will be operations that can be closed down or ignored for a period of weeks (or longer). Among the remaining operations, further analysis may be required to determine if there are others whose purpose has questionable importance to immediate survival of a production capability. To provide an example, a typical industrial facility might have departments, groups, divisions, etc., that would execute the following operations:

Security	Personnel	Maintenance
Accounting	Safety	Public Relations
Purchasing	Quality Control	Marketing & Sales
Shipping	Utilities	Transportation/Dispatch
Receiving	Production	

At the next step, these operations are organized according to some kind of rating system that clearly identifies which operations require no further analysis to warrant their suspension for a while. A typical classification for the second step might be as follows (though classification schemes may vary from plant to plant and by type of operation):

1. Necessary on a day-to-day basis to produce the basic product or service of the company (Examples - Production, Utilities)

2. Necessary infrequently to produce the product or service of the company (Examples - Purchasing, Receiving, Quality Control, Maintenance)

3. Not necessary but has equipment and/or personnel that will be valuable for emergency response (Examples - Transportation, Shipping, Non-production Personnel, Safety)

4. Necessary in the long term but can be shut down temporarily (Examples - Accounting, Security, Marketing and Sales, Public Relations)

By this process large segments (e.g., the operations under items 2 and 4) can be identified as not actually requiring an essential processes and equipment analysis. In this procedure, one must be careful not to overlook some items of equipment that may be necessary to initiate post-disaster recovery but that are not immediately vital for production. Typical examples of this sort of item might be: medical equipment, maintenance equipment and spare parts, rigging and repair equipment, communications equipment. Thus, Security and Maintenance may have exactly the kind of equipment and tools that would be most useful in a recovery period and that should be a high priority to remove to a low risk evacuation area for that purpose.

Having eliminated those functions that are obviously nonessential, the next step is to make an inventory of those essential processes to select specific items of equipment that will be most necessary post disaster and that will require protection. To assist in this task an essential equipment inventory worksheet, presented in Figure V-4, has been developed.

Taking each column on the form in turn:

NUMBER - Give each item a number. In the case of multiple items of the same type, all can be given the same number, and all treated alike. It should be noted that where several similar items exist it may only be required to protect a few of them. Only those that are to be protected should be on the list. Identify the specific units selected so the right (best) units will be the ones hardened.

E+RR - refers to the essential and replacement and repair ratings that assist in determining whether an item of equipment needs to be protected or not. A brief description of the rating system is presented below.

Essential Ratings

"1 **Absolutely Essential** - Equipment required to operate either during the disaster period for emergency response, or after to ensure survival supplies for the population. Also includes one-of-a-kind items of equipment for which there is no substitute".

Equipment required to operate during a disaster might include: emergency communications equipment, medical and fire response vehicles, emergency power generators, and in the case of nuclear threat certain types of military support

ESSENTIAL EQUIPMENT INVENTORY WORKSHEET (E+RR = 5 OR LESS)

NUMBER	E+RR	EQUIPMENT NAME & DESCRIPTION	QTY	WEIGHT (W) in lbs	HEIGHT (H) in ft	LENGTH* (L) in ft	DEPTH (D) in ft	REMARK

*Use Longest Horizontal Dimension

Fig. V-4. Essential Equipment Inventory Worksheet.

equipment. For the essential equipment survey in individual, however, the following criteria should be used. If it is the only one of its kind in the facility, is essential to the process, and if you do not know where to obtain another one or how to jury rig another one quickly, it should be included in the Absolutely Essential category.

> "2 **Essential to the Process** - Equipment that is key to some step in the production process which would stop all regular production immediately if it were eliminated, but would not make it impossible to jury rig an alternate process with lower output. (One of a kind in-plant for current production levels, but do-able via alternate process.)"

An example of this type of equipment might be a boiler in a food processing plant that could be replaced, with some effort and loss of production rate, with a portable steam supply. An example of this occurred at a local electronics plant when an accident destroyed the in-plant boiler and an old locomotive was brought in to supply steam while it was being repaired. Other examples are the automatic washing and cleaning equipment used in many production processes, which could be replaced with less efficient hand operations.

> "3 **Essential for Normal Operations** - Equipment that is required principally for normal operation of the plant, but for which there are several of a kind in-plant with production rate affected by numbers available."

Examples of this type of equipment would be a production line that consisted of a number of identical machines, e.g., milling machines or drill presses, or where there are several of the same type of equipment at various locations in the plant.

> "4 **Non-Essential** - Backup equipment used only for occasional peak demand periods or old outdated equipment."

On the surface this is an obvious category, but as will be noted later in the protection and hardening section it may be necessary to relook at some of these items of equipment. Typically, equipment in this category is older than the equipment currently in the process lines, and usually it contains less sophisticated controls and is often more ruggedly constructed. Upon analysis, in some cases, it may be more desirable to protect some items of this equipment because they will be easier to protect.

Repair/Replacement Ratings

"1 **Impossible** - refers to those items not repairable without new parts from outside and outside help."

"2 **Difficult** - Includes those items that would be better sent outside for repair or replacement work, but might be replaced or repaired with some difficulty by in-plant personnel using materials and equipment on hand."

"3 **Possible** - Includes those items that could be repaired by in-house personnel without too much difficulty using materials and equipment on hand."

"4 **Easy** - Refers to items for which many spares or substitute parts are commonly available both onsite and off and which can be repaired with resources on hand, or by simple jury rigging common materials."

With regard to those items of equipment that should be included in the essential list, for the most part, an item with a rating of 2 to 5 warrants consideration as essential, while some 5's and all items rated 6 or over should be considered non-essential for planning purposes.

EQUIPMENT NAME & DESCRIPTION - Use names commonly used in the facility to reduce confusion. Use model and make designations where possible.

QUANTITY - List the number of similar items of equipment that must be protected. Do not include extra or surplus items of similar equipment.

WEIGHT - List actual weight if known, best estimate otherwise.

HEIGHT - List height, less any easily removable projections, knobs, etc., since these will be removed as part of the protective housekeeping activities to be described later.

LENGTH - Use longest horizontal dimension - again, less easily removable appendages.

DEPTH - Other horizontal dimension - again, less appendages.

REMARKS - Any information that would assist the planners. This would include the type of structure around the item of equipment, how it is fastened to the floor, shut-down time, etc.

An example of a filled-out form, for a typical high technology firm, is shown in Figure '/-5.

Step 3 - VULNERABILITY ASSESSMENT

The primary purpose of Step 3, the vulnerability assessment of individual items of industrial equipment, is to identify those items of equipment that do not need protection (which won't amount to very many items) and to assist in the selection of countermeasures. The calculations are simple, and to assist in the process an essential equipment vulnerability worksheet has been developed, see Figure V-6. Describing each column in turn:

NUMBER - Once again, a numbering system is necessary to allow the items of equipment to be identified and to reduce the amount of information that needs to be duplicated from sheet to sheet.

EXPOSED AREA IN SQ FT - Multiply the height times the greatest horizontal dimension (H x L on the inventory worksheet, both in feet).

WEIGHT/UNIT AREA IN LB/SQ FT - Divide weight (W on the inventory worksheet) by exposed area, obtained in step above.

DENSITY FACTOR (F) - Divide weight (W) by the dimension in feet of Height (H) times length (L) times depth (D), all obtained from the inventory worksheet, and multiply by 0.002. (It also equals 0.002/D x W/A.)

SURVIVABILITY - Using weight/unit area value obtained above, find survivability rating from vulnerability/survivability table. When W/A falls between ranges use the closest value in the table to determine S. For example, if W/A = 248, use S = 5, and when W/A = 251, use S = 6.

ESSENTIAL EQUIPMENT INVENTORY WORKSHEET (E+RR = 5 OR LESS)

NUMBER	E+RR	EQUIPMENT NAME & DESCRIPTION	QTY	WEIGHT (W) in lbs	HEIGHT (H) in ft	LENGTH* (L) in ft	DEPTH (D) in ft	REMARK
1	2	HYDRAULIC PRESS / BRAKE	1	23,000	8.42	10.7	5.1	BOLTED TO FLOOR
2	2	HYDRAULIC SHEAR	1	30,800	6.67	10.6	8.2	BOLTED TO FLOOR
3	2	MULTIPLE SPINDLE DRILL PRESS	1	2,350	7.67	10.5	2.0	BOLTED TO FLOOR
4	2	ENGINE LATHE	1	3,200	4.4	8.3	2.5	BOLTED TO FLOOR
5	2	TURRET LATHE	1	5,300	5.0	10.1	5.3	BOLTED TO FLOOR
6	4	LEAK DETECTOR	1	490	3.2	2.4	1.7	ON CASTERS
7	4	TIG WELDER	6	476	2.3	2.8	1.8	FREE STANDING
8	2	SPOT WELDER	1	200	4.7	3.3	2.0	BOLTED TO FLOOR
9	3	POWER ROLL BENDING	1	1,170	4.5	7.8	1.6	BOLTED TO FLOOR

*Use Longest Horizontal Dimension

Fig. V-5. Completed Essential Equipment Inventory Worksheet.

ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET

NUMBER	EXPOSED AREA IN SQ FT	WEIGHT/UNIT AREA IN LBS/SQ FT (W/A)	DENSITY FACTOR (F) = 0.002W/DHL	SURVIVABILITY SEE TABLE*

*Where W/A falls between listed values, use S for the smaller listing

VULNERABILITY/SURVIVABILITY TABLE

W/A	S
30	1
60	2
110	3
160	4
220	5
280	6
360	7
440	8
530	9
630	10
760	11
900	12
1100	13
1300	14
1500	15

Fig. V-6. Essential Equipment Vulnerability Inventory Worksheet.

An example of a filled out form for a typical high technology firm (the same one shown in Figure V-5) is shown in Figure V-7.

Step 4A: SELECT COUNTERMEASURES (Shutdown Facility)

A variety of countermeasures can be used to protect essential industrial equipment in a facility that can be shut down during a crisis period. (Techniques for facilities that must remain in operation during the crisis period are given in Step 4B.) These countermeasures are primarily a means for changing the environment of the item of equipment. A list of such countermeasures follows in a general order of increasing level of effort to implement, excluding items 1 and 11.

1. Protective housekeeping
2. Reorienting
3. Isolating (move outside and away from other equipment and structures)
4. Clustering
5. Evacuating
6. Clustering with sandbag revetment or soil berm
7. Berming individually
8. Trenching
9. Packaging and anchoring
10. Burial
11. Facility upgrading

1. Protective Housekeeping

Under protective housekeeping a number of activities are performed. Among the most important of these are:

Ensuring that there is a minimum of loose material lying around that can become potentially hazardous missiles under the dynamic (wind) pressure of the blast wave

Removing or covering vulnerable gauges, controls, handles, and other fragile appendages to minimize the damage that may occur to the equipment under the action of missiles or other impact forces

ESSENTIAL EQUIPMENT VULNERABILITY WORKSHEET

NUMBER	EXPOSED AREA IN SQ FT	WEIGHT/UNIT AREA IN LBS/SQ FT (W/A)	DENSITY FACTOR (F) = 0.002W/DHL	SURVIVABILITY SEE TABLE*
1	90.1	255	0.100	6
2	70.7	436	0.106	8
3	80.5	29.2	0.029	1
4	36.5	87.7	0.070	3
5	50.5	105	0.040	3
6	7.7	63.6	0.075	2
7	6.4	74.4	0.082	2
8	15.5	12.9	0.013	1
9	35.1	33.3	0.042	1

*Where W/A falls between listed values, use S for the smaller listing

VULNERABILITY/SURVIVABILITY TABLE

W/A	S
30	1
60	2
110	3
160	4
220	5
280	6
360	7
440	8
530	9
630	10
760	11
900	12
1100	13
1300	14
1500	15

Fig. V-7. Completed Essential Equipment Vulnerability Inventory Worksheet.

Unhooking power and fuel lines

Removing flammable material

Disconnecting long conductors, such as antennas and power cables, from electronic and electrical equipment (or installing EMP protection on communication equipment)

Protecting critical equipment repair and maintenance records

As discussed above, it is desired to protect the equipment from all nuclear weapons effects and that although blast is by far the most serious, some of the above measures are slanted towards minimizing fire effects. <u>It also should be noted that in calculating the survivability values it is always assumed that the protective housekeeping countermeasure is carried out.</u>

2. Reorienting

For any item of equipment whose height is significantly greater than either of the other two dimensions the survivability can be significantly increased by turning the equipment on its side so that the minimum dimension of the equipment becomes the height (see Figure V-8). This is particularly helpful for one class of equipment, i.e., that which is susceptible to severe damage by the simple process of overturning and impacting the ground surface. Typically such equipment has a height much greater than either of the other two dimensions and it also contains sensitive elements near the top of the equipment. The degree of survivability increase depends on the equipment characteristics but can easily be an increase of 2 to 4.

To test whether items of equipment, which fit the above criteria, can survive using only this countermeasure, recalculate their survivability using the equipment inventory and equipment vulnerability worksheets. In practice this can be done on the sheets already filled out.

3. Isolating (move outside and away from other equipment and buildings)

This countermeasure works by eliminating the possibility of the equipment impacting other equipment or parts of the structure; it also eliminates the possibility of heavy items and parts of the structure impacting the equipment; e.g., from the roof collapsing or fragments of the wall hitting it (see Figure V-9). Typically, this

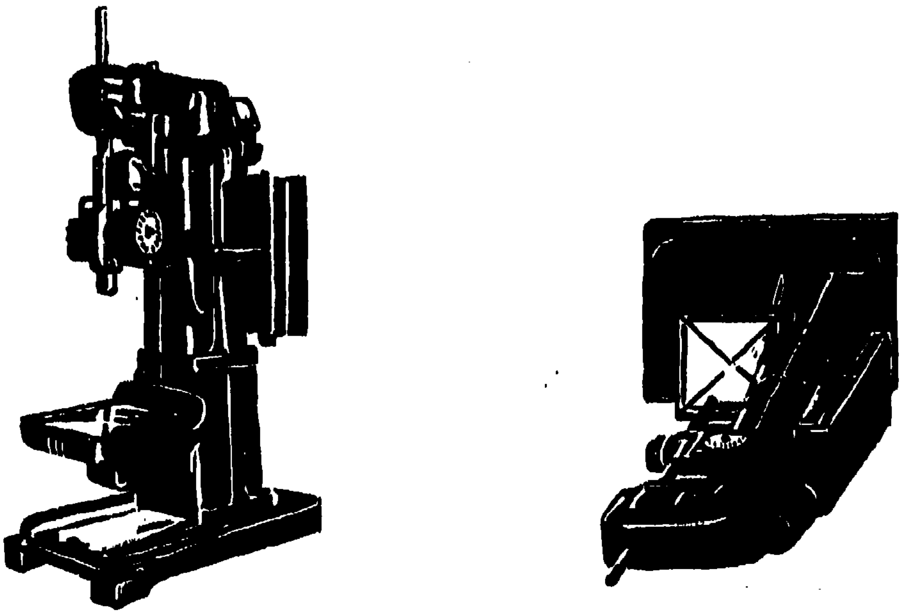


Fig. V-8. Reorienting.

Fig. V-9. Isolating.

doubles the survivability, and this increase will be over and above any increases due to the reorienting countermeasure. Isolating will not be very effective unless you have a couple of hundred feet of clear space around the isolated item or isolated cluster (see next countermeasures).

4. Clustering

One of the most promising onsite hardening techniques where burial is not feasible is to cluster the equipment in an open area (such as a parking lot) and to secure all items together by means of banding, strapping, or welding (see Figure V-10). Providing that the cluster can be adequately secured as a unit, all elements within it will become very much less vulnerable than standing alone. First, moving the equipment outdoors away from other buildings and equipment greatly increases its survivability, as described above for the isolating countermeasure. Second, its vulnerability to the remaining damage mechanisms is greatly decreased because the cluster is much more difficult to overturn and requires much higher pressures to cause impact with the same velocities as for individual equipment items. Note that buffering material such as sandbags needs to be placed between individual items in the cluster to prevent their impacting one another. If, for some reason, the cluster has to be left inside a building, shielding should be added to the top and sides to minimize the damage from roof collapse and wall fragments. If resources for shielding are limited, put nonessential equipment around the outside of the cluster.

The survivability levels for clusters of various sizes and weights are determined from Figure V-11. It can be seen that survivability depends on the size (S) of the cluster (which is taken as its minimum horizontal distance) and the ratio (F_c) of the average density of the cluster to that of steel. Note that F_c can be obtained by adding all the density factors, F, for each item of equipment to be placed in the cluster (calculated on the equipment vulnerability worksheets) and dividing by the total number of items in the cluster. An upper working limit to the survivability of equipment in a cluster is 25 to 35 psi because there may be difficulty in holding a cluster larger than 18 to 25 feet per side together. Clustering is a very important countermeasure when items of equipment are too heavy to move.

5. Evacuating

If the manpower and transportation facilities are available to move the equipment to a safe location in the host area then do it; this is an ideal countermeasure (see Figure V-12).

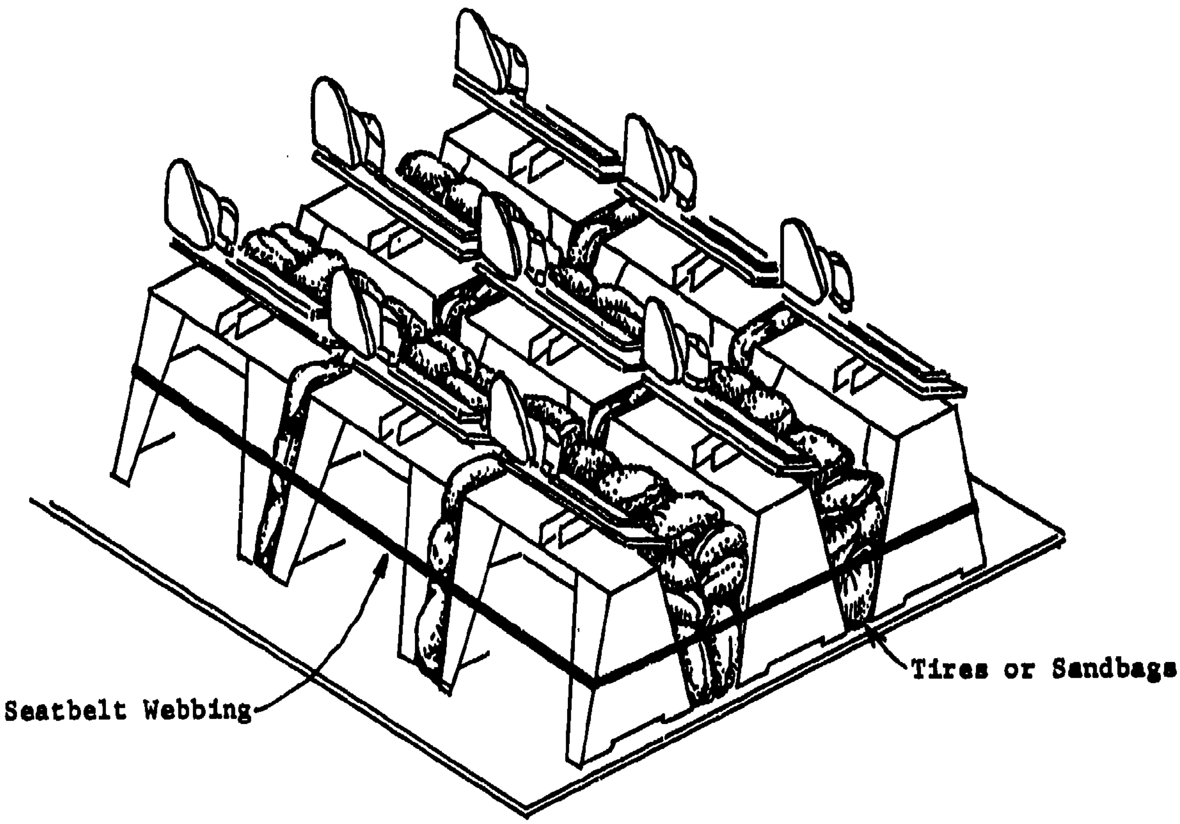


Fig. V-10. Clustering.

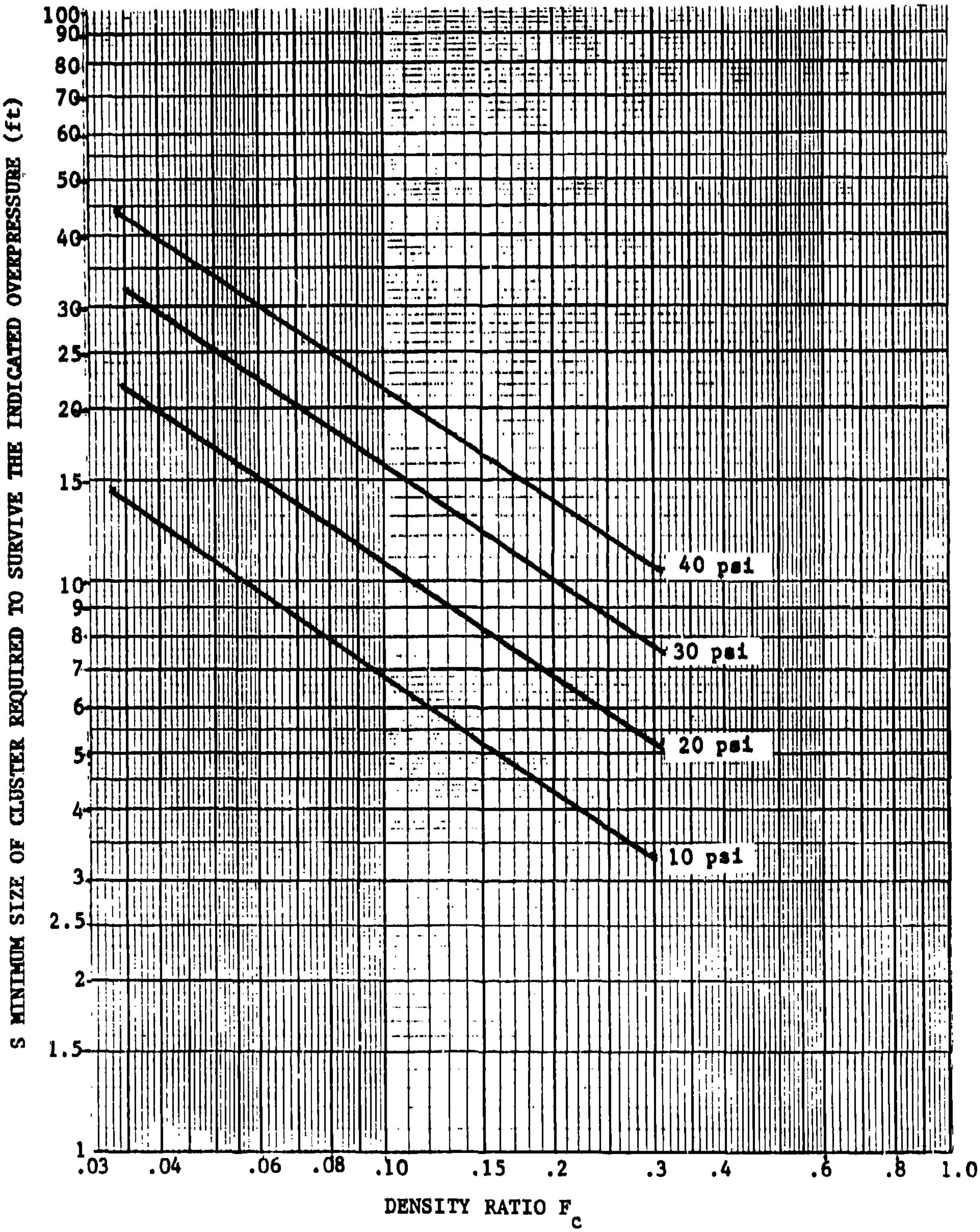


Fig. V-11. Survival Levels of Clustered Equipment for a 500 kt Weapon.

6. Clustering With Sandbag Revetments

This will likely require more effort than evacuating. Where equipment is too heavy to move or egress routes are limited, it could prove an extremely important countermeasure. The addition of a sandbag revetment to about the height of the equipment (with a slope of about 1 ft rise in 4 ft) helps ensure that the cluster retains its integrity and increases still further its survivability. It is estimated that, with the sandbag revetment, clusters can survive up to 30 to 40 psi overpressure (see Figure V-13). It is interesting to note that if the revetment is made a few feet higher than the cluster and the space inside is filled with soil, this countermeasure becomes an above grade burial condition, which increases survivability to 300 psi.

7. Berming

A simple earth berm completely around each item of equipment will offer protection from fragments and also overpressure. This protection measure enabled equipment to survive 20 psi from a large high explosive test (500 tons). The items of equipment need to be tied together, however, to prevent them from moving and hitting one another.

8. Trenching

A corollary to berming, trenching is also an excellent method for protection from fragments and overpressure (see Figure V-14). With this method equipment survived 20 psi in the test noted above. Again the equipment needs to be restrained.

9. Packaging and Anchoring

This involves placing stacks of material (e.g., lumber) around the equipment to protect it from missiles, then wrapping seatbelt webbing around the package and fastening this to expedient anchors to prevent movement under the blast loading (see Figure V-15).

10. Burial

This, too, may require more effort and equipment than evacuating, but could prove valuable in some instances. Burial of equipment, preferably surrounded by crushable material, under a several ft thick layer of dirt is one of the two best countermeasures along with evacuation in the sense of providing the greatest blast protection. It is expected that without packing in crushable material the survivability of equipment using this countermeasure is 40 to 80 psi and with packing, greater than 300. Note that the equipment needs to be securely wrapped in heavy

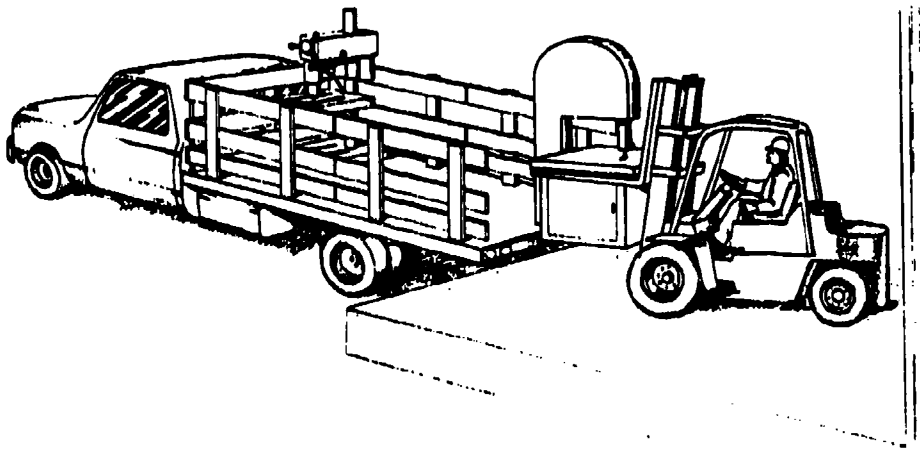


Fig. V-12. Evacuating.

Fig. V-13. Clustering With Sandbag Revetments.

Fig. V-14. Trenching.

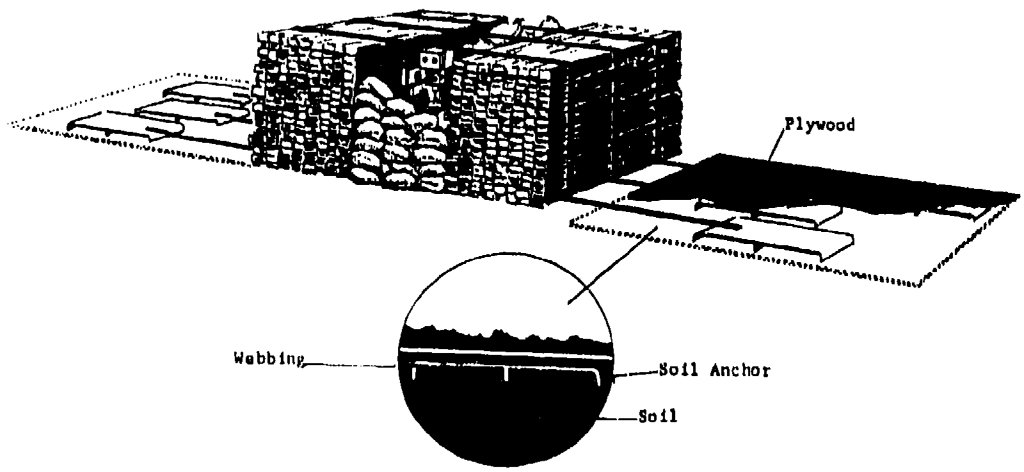


Fig. V-15. Packaging and Anchoring.

plastic before burial to protect it from the dirt or sand and, in particular, moisture. (See Figure V-16.)

11. Facility Upgrading

Many facilities can be upgraded to reduce their vulnerability to nuclear effects. This requires below grade space or a basement area (see Figure V-17). Techniques for upgrading are given in a later section of this Part V.

Step 4B: SELECT COUNTERMEASURES (Operating Facility)

There will be a substantial number of facilities that will be required to operate throughout the crisis period up to an attack warning, and a smaller number that will need to operate through the attack. In the first group might be included: military support operations, food suppliers, and utilities. The second group would include communications and emergency response facilities.

The first group will require shelters for the key workers who remain behind to operate the facilities and if possible hardened facilities for the equipment as well. The second group definitely requires hardened facilities for the entire operation.

Many of the previously discussed countermeasures are valid for a facility that must be kept operating. These include:

1. Protective Housekeeping
2. Isolating
3. Evacuation
4. Berming
5. Trenching
6. Facility Upgrading

1. Protective Housekeeping

Many of the protective housekeeping measures are still valid for an operating facility. These would include cleaning up around the area to reduce the hazards of fires and missiles, removing from the area all hazardous materials, and tieing down all materials and equipment not specifically required for the emergency operations.

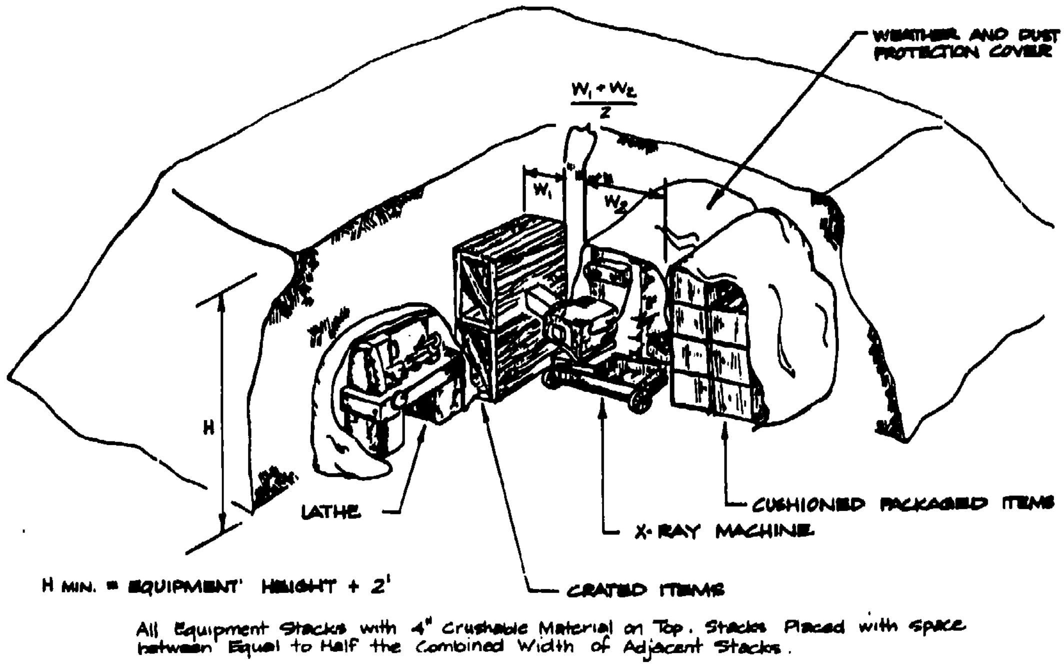


Fig. V-16. Burial.

Fig. V-17. Facility Upgrading.

2. Isolating

Many operations can be isolated, either by removing unnecessary materials from the vicinity of the equipment, or by moving the operation outside away from a structure that is likely to damage the equipment if an attack occurs.

3. Evacuation

This is a very valid countermeasure more often than is realized. Many operations can easily be moved outside the risk area in a very short period of time. Machine shops, for example, have been moved in a day, entire warehouses of materials have been moved, because of imminent floods and huricanes, in a matter of hours. For many operations this is a viable option and should be investigated.

4. Berming

A simple earth or sandbag berm will offer protection from fragments and overpressure and would allow the equipment to still be operated.

5. Trenching

This is a less viable alternative from a practical point of view because it requires the equipment to be moved, and if it can be moved, evacuation might be a better solution. It has been demonstrated on mobile equipment at 20 psi, as shown in Figure V-18.

6. Facility Upgrading

Many facilities can be upgraded to reduce their vulnerability to nuclear effects. In general, for the higher threat levels, a belowground facility will be required. As noted, techniques for upgrading are given in a later section.

A summary of the various countermeasures and the expected survivability ratings is presented in Table V-2.

The question may have occurred to the reader by this time whether there is anywhere near enough time to implement the various countermeasures described above in actual practice. To answer this question it may be noted that, in a number of different types of industrial plants actually studied in detail, it was found possible (in some cases by actual test and others by analysis) to carry out hardening plans in between 1 and 3 days using the same types of countermeasures discussed above.

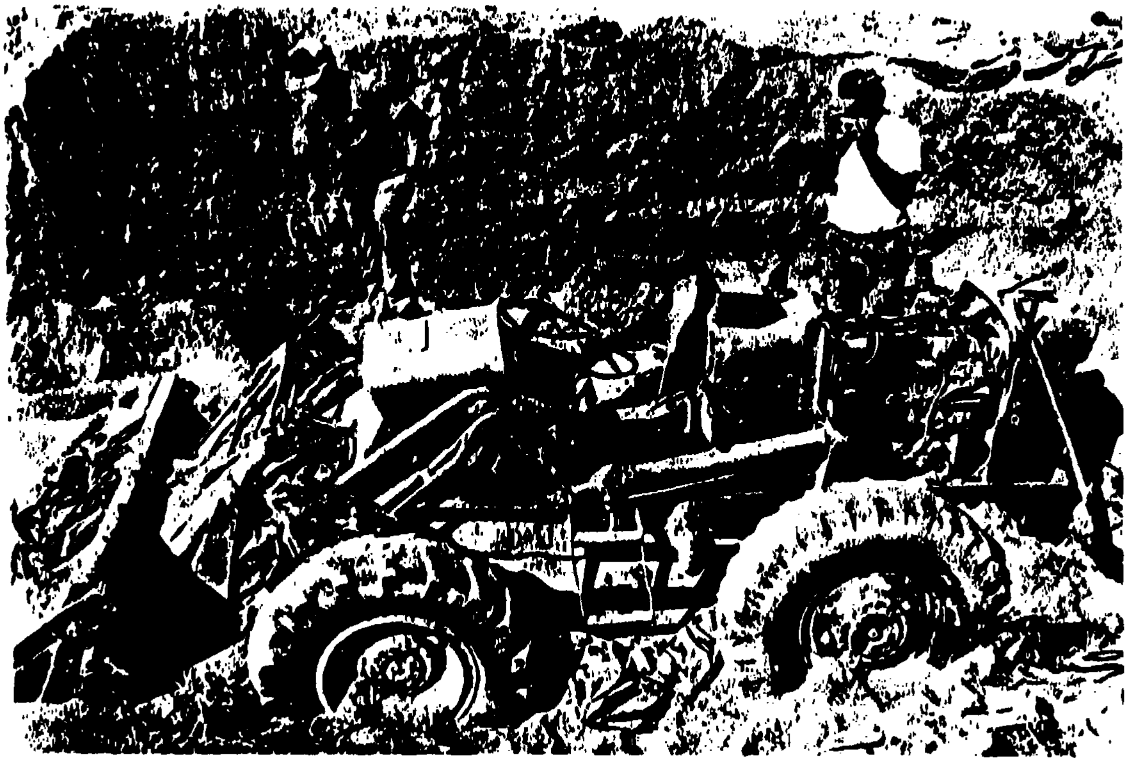


Fig. V-18. Protection of Mobile Equipment in a Trench.

Table V-2
SUMMARY OF COUNTERMEASURES

Countermeasure	Survivability Rating (psi)
Reorienting	Note 1
Isolating	Note 1
Clustering	25 - 35
Evacuating	Note 2
Clustering with sandbag revetment	30 - 40
Berming	20
Trenching	20
Packaging and anchoring	20
Burial	40
Burial with crushable material	300

Note 1 - Must be calculated
Note 2 - No longer at risk

Figure V-19 presents the Countermeasures/Resources Worksheet, and a sample completed worksheet for the plant used in the previous examples is shown in Figure V-20. It will be noted that estimates have been made for the equipment, materials, and labor required to implement the various countermeasures. The final note on countermeasure selection is DO THE PLANNING NOW - WELL IN ADVANCE OF THE CRISIS PERIOD. THIS WILL GIVE AMPLE TIME FOR COMPARISON OF ALTERNATIVE COUNTERMEASURES AND DEVELOPMENT OF THE FINAL HARDENING PLAN AS WELL AS FOR STOCKPILING ITEMS NECESSARY FOR IMPLEMENTING THE SELECTED COUNTERMEASURES.

COUNTERMEASURES/RESOURCES WORKSHEET

NUMBER	S	COUNTERMEASURE	LABOR REQUIREMENT		MATERIAL REQUIREMENT		EQUIPMENT REQUIREMENT		TIME HOURS
			TYPE	HOURS	TYPE	QUANTITY	TYPE	QUANTITY	

Fig. V-19. Countermeasures/Resources Worksheet.

COUNTERMEASURES/RESOURCES WORKSHEET

NUMBER	S	COUNTERMEASURE	LABOR REQUIREMENT TYPE	LABOR REQUIREMENT HOURS	MATERIAL REQUIREMENT TYPE	MATERIAL REQUIREMENT QUANTITY	EQUIPMENT REQUIREMENT TYPE	EQUIPMENT REQUIREMENT QUANTITY	TIME HOURS
1	35	24 X 26 CLUSTER	1 LABORER	2			BOLT CUTTERS	1	2
2	35	24 X 26 CLUSTER	2 LABORERS	1			FORKLIFT	1	1
3	35	24 X 26 CLUSTER	2 WELDERS	2	6" X 15.3 LB CHANNEL 4" X 7.25 LB CHANNEL	12 EA-20FT 10 EA-2 FT	WELDER	2	2
4	35	24 X 26 CLUSTER	2 WELDERS	2	6 FT CHAIN LINK FENCE	220 FT	WELDER	2	2
5	35	24 X 26 CLUSTER	4 LABORERS[a]	3	SANDBAGS	700	SHOVELS	4	3
6	35	24 X 26 CLUSTER	2 LABORERS	4	SAND OR SOIL	12 YDS	PICKUP # 1 PRIVATE AUTOS	1 2	2 1
7[b]	35	4 EA IN CLUSTER 2 EA EVACUATE					FORKLIFT PICKUP # 1	1 1	.25
8	SAFE	EVACUATE	3 LABORERS	.25	FILLED 5 GAL GAS CANS	6	PRIVATE AUTOS	2	
9[b]	SAFE	EVACUATE	4 LABORERS	.25	STRAPS OR WEBBING	100 FT	FORKLIFT PICKUP # 1	1 1	.25

a. Sandbag filling must start when bolt cutting starts.

b. Two TIG Welders used to make cluster to be loaded on Pickup #1 together with items 9 and 10 and their R & D counterparts. Forklift is required for loading pickups, and is to be in the cluster also, so that all these items must be loaded on Pickup #1 before final welding of channel.

NOTE: Last minute items and tools to be evacuated to private auto. Caravan of two pickups plus autos from site to Host Area.

Fig. V-20. Completed Countermeasures/Resources Worksheet.

Section 2
HARDENING BELOW-GRADE ROOMS

UPGRADING TO LESS THAN 20 PSI

Criteria for Selecting Candidate Areas for Upgrading

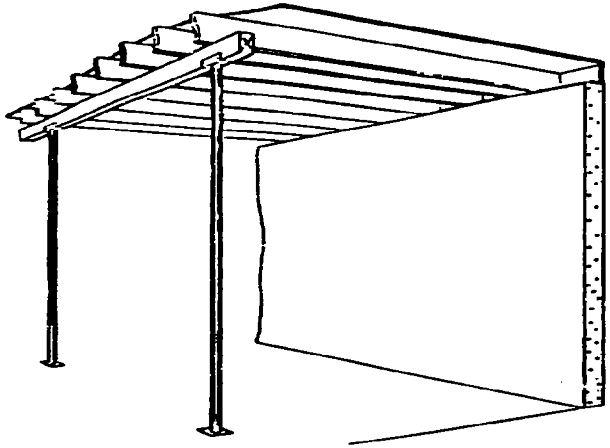
In order that an building area be a viable candidate for upgrading to the protective level required, it must meet several basic requirements. The area must be located below grade, the walls must be constructed of reinforced concrete or concrete masonry block units, and the floor system above the candidate area must possess the capability to be upgraded by shoring to the desired survival level. An area would be considered below grade provided that the earth level against the exterior walls is not less than 2 ft below the upper surface of the floor above. A berm to provide the addtional 2 ft will be required.

Figures V-21 through V-2[illegible] [illegible] the eleven floor systems that are considered acceptable in this pressure range for upgrading with shores. Each system has an ajacent table that indicates the survival overpressure in psi when "SHORED" (upgraded), and "AS-BUILT" (without upgrading), for two separate DESIGN OCCUPANCY LOADINGS. These loadings are designated "LIGHT" and "MEDIUM". This designation refers to the load the design engineer used (which was based on the ORIGINAL INTENDED OCCUPANCY) to design the floor's load capability. "LIGHT" occupancy includes floors that were designed for loads of 40 to 60 psf, while "MEDIUM" occupancy includes floors designed for 80 to 125 psf. Table V-3 lists a number of the occupancies, based on building code tables, associated with each of these designations.

Another factor that should be considered in selecting an area for upgrading is the number of openings that will need to be closed off to maintain the protective area's integrity. An excess number of openings will expend significant upgrading resources. Also, the floor-to-ceiling height should not exceed 12 ft.

Finally, the floor slabs below and overhead should not contain any major structural defects.

SAWN LUMBER JOIST FLOOR

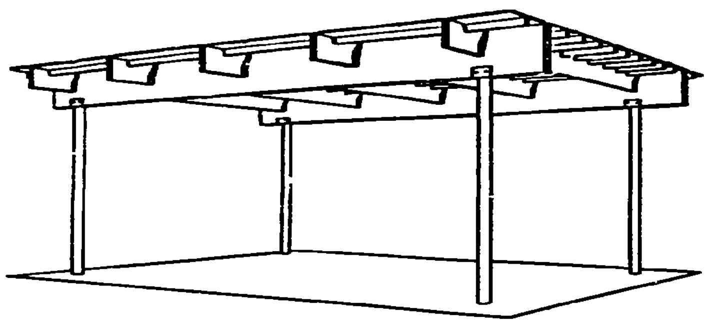


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	10
MEDIUM	3	14

SHORING TYPE - P & B

A

GLULAM TIMBER JOIST FLOOR



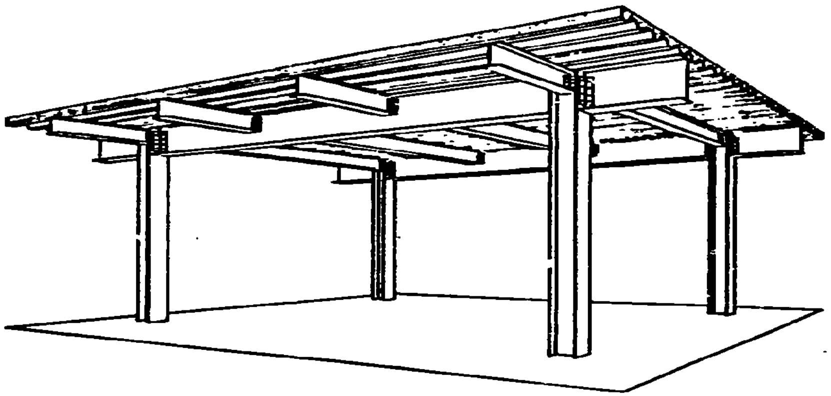
DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	9
MEDIUM	2	17

SHORING TYPE - P & B

B

Fig. V-21. Timber Floor Systems.

HEAVY STEEL BEAM & SLAB FLOOR

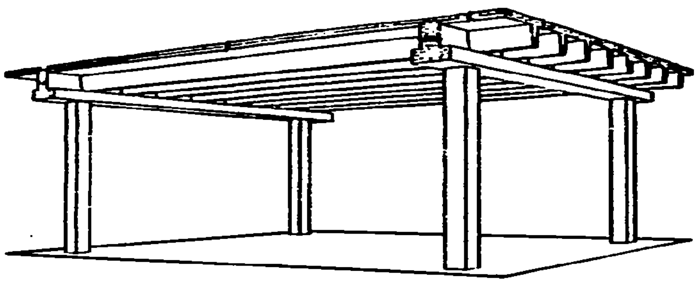


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	8
MEDIUM	2	14

SHORING TYPE - P & B

A

PRECAST PRESTRESSED CONCRETE SINGLE & DOUBLE TEE FLOOR



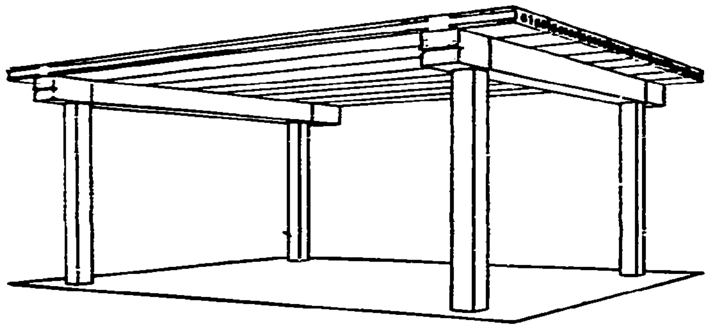
DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	19

SHORING TYPE - P & B

B

Fig. V-22. Heavy Steel Beam & Slab and Single & Double Tee Floors.

PRECAST PRESTRESSED HOLLOW-CORE SLAB FLOOR

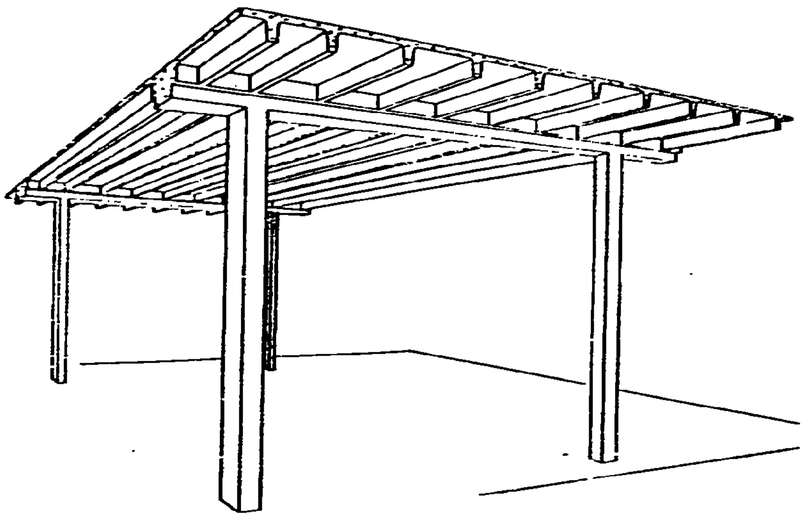


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	17
MEDIUM	3	20

SHORING TYPE - P & B

A

REINFORCED CONCRETE ONE-WAY JOIST FLOOR



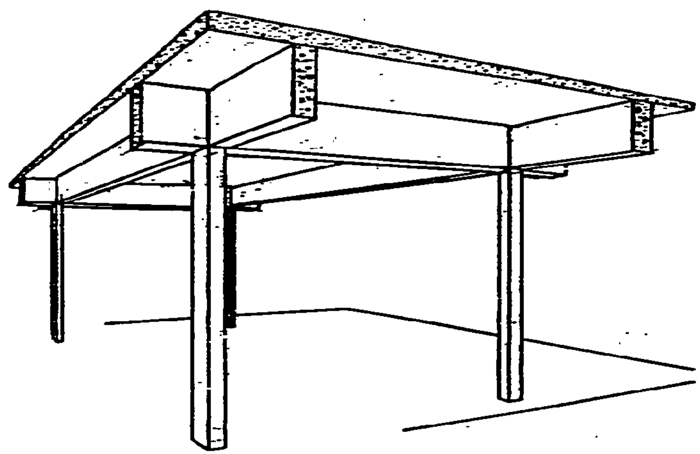
DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	19

SHORING TYPE - P & B

B

Fig. V-23. Concrete Floor Systems.

REINFORCED CONCRETE ONE-WAY SOLID SLAB FLOOR

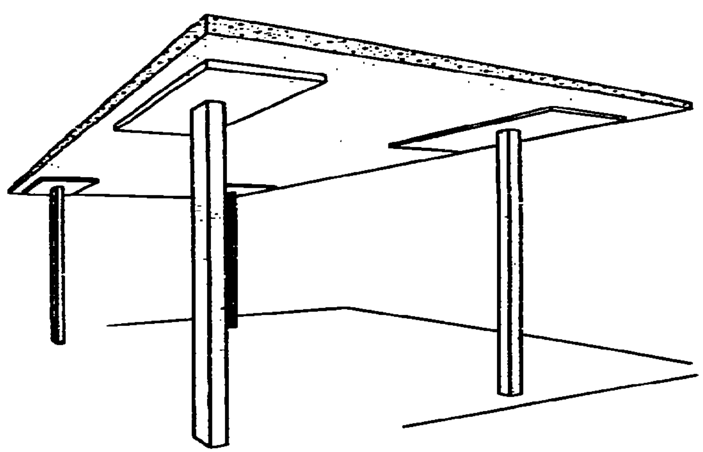


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	19

SHORING TYPE - P & B

A

REINFORCED CONCRETE FLAT SLAB FLOOR



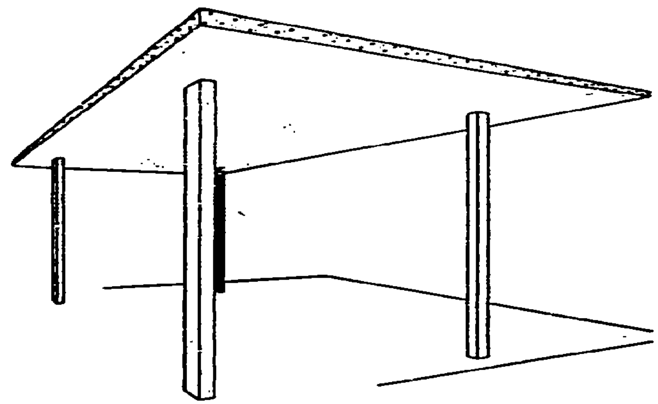
DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	18

SHORING TYPE - P

B

Fig. V-24. Concrete Floor Systems.

REINFORCED CONCRETE FLAT PLATE SLAB FLOOR

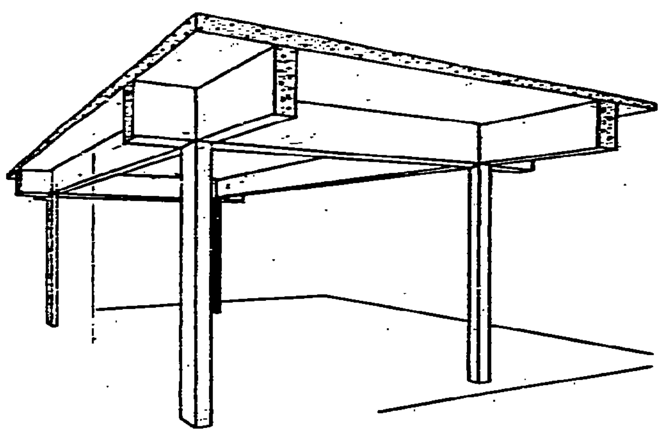


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	18

SHORING TYPE - P

A

REINFORCED CONCRETE TWO-WAY SOLID SLAB FLOOR



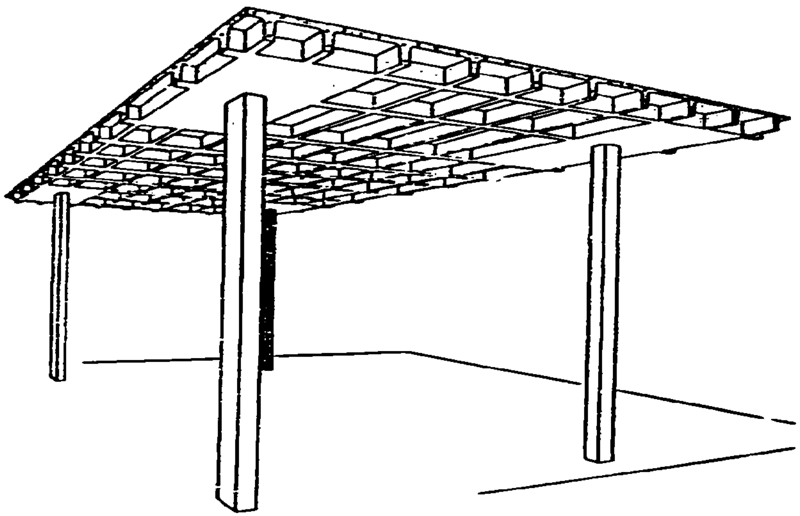
DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	18

SHORING TYPE - P

B

Fig. V-25. Flat Plate and Two-Way Solid Slab Floor Systems.

REINFORCED CONCRETE WAFFLE SLAB FLOOR



DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED
LIGHT	1	12
MEDIUM	2	18

SHORING TYPE - P

A

Fig. V-26. Concrete Waffle Slab Floor System.

Table V-3

OCCUPANCIES FOR EACH LOAD GROUP

LIGHT 40 to 60 psf	MEDIUM 80 to 125 psf
Assembly Areas & Auditoriums w/Fixed Seats	Assembly Areas & Auditoriums w/Movable Seats & Stages
Apartments	Dance Halls & Ballrooms
Hospital	Dining Rooms & Restaurants
Hotel/Motel Guest Rooms	Gymnasiums
Libraries - Reading Rooms	Libraries - Stackrooms
Office Buildings - Offices	Manufacturing - Light
Private Dwellings	Office Buildings - Lobbies
Schools	Printing Plants
Parking Garages	Skating Rinks
	Storage - Light
	Stores - Retail & Wholesale

Shoring Methodology

Because of structural considerations, particular types of floor constructions must be shored only with certain shoring configurations. A floor construction defined as a one-way system, i.e., the principal structural members, or principal reinforcement in the case of concrete, run in one direction only, require lines of shoring the full width of the bay, perpendicular to the direction of the principal members or reinforcement. Shoring of these types of construction is accomplished by using **POST & BEAM** shoring, and is appropriate for the following floor systems:

SAWN LUMBER JOIST FLOORS
GLULAM TIMBER JOIST FLOORS
HEAVY STEEL BEAM & SLAB FLOORS
PRECAST PRESTRESSED CONCRETE SINGLE & DOUBLE TEE FLOORS
PRECAST PRESTRESSED CONCRETE HOLLOW-CORE SLAB FLOORS
REINFORCED CONCRETE ONE-WAY JOIST FLOORS
REINFORCED CONCRETE ONE-WAY SOLID SLAB FLOORS

Each of the above floors has a **SHORING TYPE - P & B** indicated on Figures V-21A through V-24A.

A floor defined as a two-way system, i.e., where the principal reinforcement in concrete runs in two directions, normally perpendicular to each other, require shoring throughout the bay symmetrically by individual posts. Shoring of these types of construction is accomplished by using **POST** shoring, and is appropriate for the following floor systems:

REINFORCED CONCRETE FLAT SLAB FLOOR
REINFORCED CONCRETE FLAT PLATE FLOOR
REINFORCED CONCRETE TWO-WAY SOLID SLAB FLOOR
REINFORCED CONCRETE WAFFLE SLAB FLOOR

Each of the above floors has a **SHORING TYPE - P** indicated on Figures V-21B through V-26.

Shoring Systems

For simplification, only specific sizes of timber shoring are presented for the two, POST & BEAM and POST, shoring configurations. Since the determination of the sizes of shoring members is based on a number of structural considerations, the use of the sizes indicated below are restricted to the following parameters:

1. The length of the span (beam to beam, beam to wall, or wall to wall) for one-way floor systems should not exceed 18 ft.

2. The dimensions of the bay, in either direction, for two-way floor systems should not exceed 24 ft.

3. The floor systems require shoring at the 1/3 spans, i.e., the one-way floor system with post & beam shoring spaced not over 6 ft on center the entire width of the shored area, and the two-way floor system with post shoring spaced symmetrically in each bay at a maximum of 8 ft on center in either direction.

4. The distance between the basement floor and the ceiling above should not exceed 12 ft.

5. All shoring should be positioned as close to vertical as possible, and requires shimming tightly between the floor and ceiling.

The sizes of the timber members required to accomplish the upgrading are as follows:

POST & BEAM SHORING
(for use in one-way floor systems)
BEAMS - 12 BY 12 IN. TIMBER
POSTS - 12 BY 12 IN. TIMBER

POST SHORING
(for use in two-way floor systems)
POSTS - 8 BY 8 IN. OR 10 IN. DIAMETER TIMBER

A shoring system, when constructed using the above indicated material sizes, and when installed in the manner and in the locations described above, will provide upgrading to the survival overpressure levels shown on Figures V-21 though V-26. When larger bay sizes or greater span lengths, or higher floor to ceiling heights, are encountered, shore spacing other than 1/3 span and shoring materials different in size from those shown above, may be appropriate. In these special cases, however, the shoring systems will be required to be re-engineered.

Closures

In order to maintain the integrity of the shored protective space, as well as to protect the equipment from possible damage from debris and dust, openings such as stairwells, elevator and ventilating shafts, windows and doors should be closed off. This may be accomplished by the use of many types of materials, including timber beams and posts, steel plate, desk and table tops, and solid doors, provided that these materials have the strength to survive the required blast overpressure loading. Chart 1 is provided herein to assist in determining the thickness of timber beams required, relative to the minimum span to be closed (you would always want to span the minimum span direction of the opening, if possible). This chart was calculated to be structurally compatible with the shoring systems described above, and accordingly, will support the survival overpressures shown on Figures V-21 through V-26.

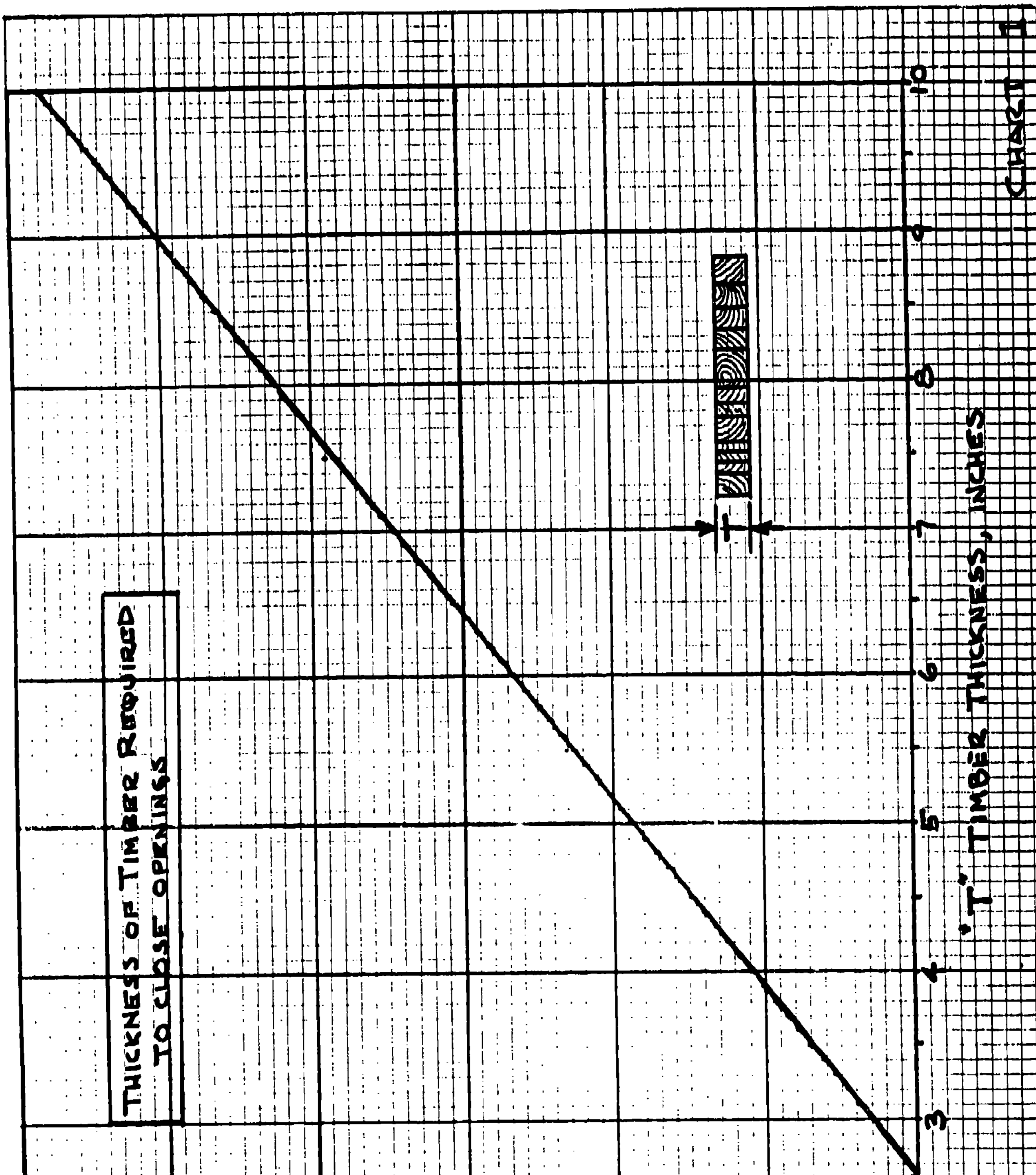


CHART II
THICKNESS OF TIMBER REQUIRED
TO CLOSE OPENINGS
"T" TIMBER THICKNESS, INCHES
MINIMUM CLOSURE SPAN, FT.
2
3
4
5
6
7
8
9
10
2
3
4
5
6
7
8
T

UPGRADING TO 30 TO 50 PSI

Criteria for Selecting Candidate Areas for Upgrading

In order that an building area be a viable candidate for upgrading to a protective level of 30 to 50 psi, it must meet several critical requirements:

1. The area must be located entirely below grade. To be considered below grade the earth le el against the exterior walls must reach to the top of or above the upper surface of the floor to be upgraded. Several feet of soil may be bermed against the outside to ensure this.

2. The walls must be constructed of reinforced concrete or concrete masonry block units.

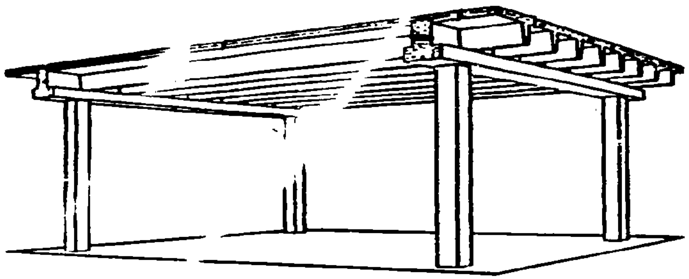
3. The floor system above the candidate area must be of concrete construction and included as one of the floor systems listed herein.

4. The floor system must have no serious structural defects.

5. The floor-to-ceiling height mst not exceed 12 ft.

Figures V-27 through V-30 list the eight floor systems that are considered acceptable for upgrading to these levels with shores. Each system has an adjacent table that indicates the survival overpressure in psi for conditions of interest to survival. These are when "SHORED" (upgraded) at the **1/3 span** and/or the **1/4 span**, and "AS-BUILT" (without upgrading), for two separate design occupancy loadings designated as "MEDIUM" and "HEAVY". This designation refers to the load the design engineer used (which was based on the original intended occupancy) to determine the floor's load capability. "MEDIUM" occupancy is defined as floors designed for loads of 80 to 125 psf, while "HEAVY" occupancy floors are designed for 150 to 250 psf. Table V-4 lists a number of recognizable occupancies, based on building code tables associated with each. Another factor that should be considered in selecting an area for upgrading is the number of openings that will need to be closed off to maintain the protective area's integrity. With the high level of overpressure under consideration in this section, 30 to 50 psi, it will be extremely difficult to close off a number of large openings, such as stairwells and elevator shafts.

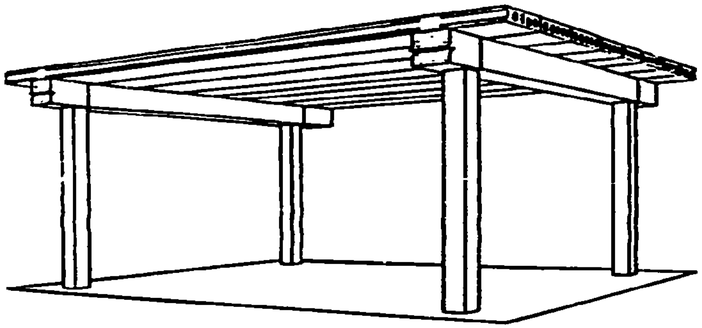
PRECAST PRESTRESSED CONCRETE SINGLE & DOUBLE TEE FLOOR



DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED 1/3 SPAN
HEAVY	4	31

SHORING TYPE - P & B

PRECAST PRESETRESSED HOLLOW-CORE SLAB FLOOR

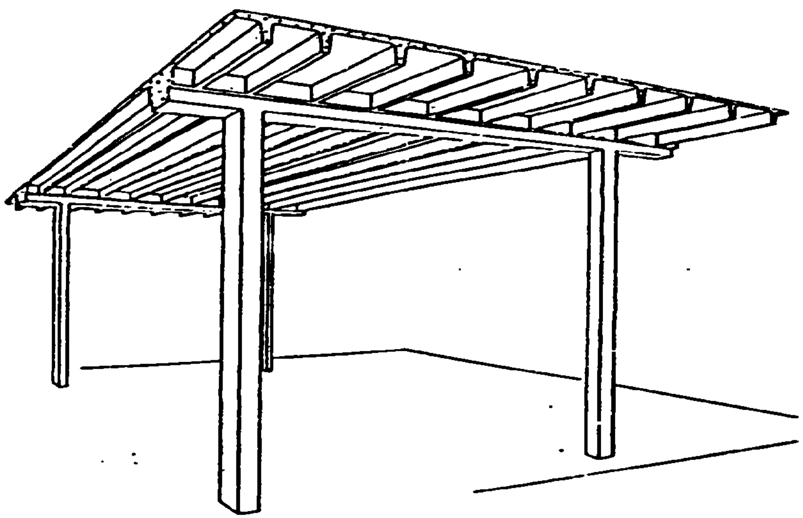


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED 1/3 SPAN
HEAVY	6	30

SHORING TYPE - P & B

Fig. V-27. Single & Double Tee and Hollow-Core Floor Systems.

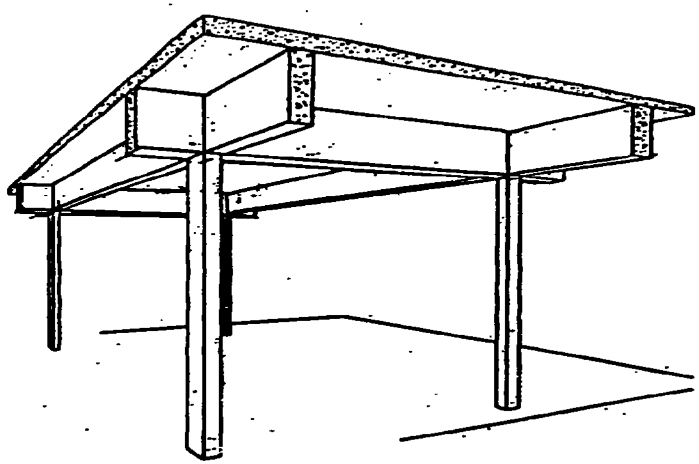
REINFORCED CONCRETE ONE-WAY JOIST FLOOR



DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED 1/3 SPAN
HEAVY	4	31

SHORING TYPE - P & B

REINFORCED CONCRETE ONE-WAY SOLID SLAB FLOOR

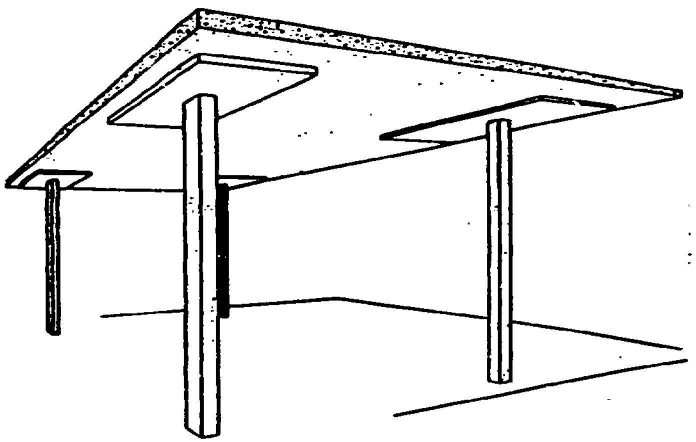


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi	
	AS-BUILT	SHORED 1/3 SPAN
HEAVY	6	36

SHORING TYPE - P & B

Fig. V-28. Reinforced Concrete One-Way Floor Systems.

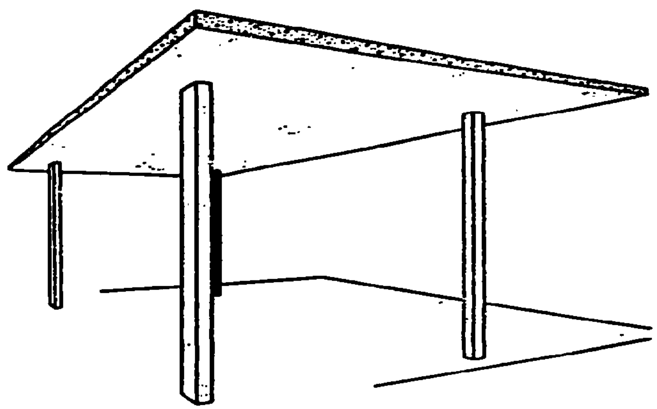
REINFORCED CONCRETE FLAT SLAB FLOOR



DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi		
	AS-BUILT	SHORED 1/3 span	SHORED 1/4 span
MEDIUM	2	NA	37
HEAVY	4	31	50

SHORING TYPE - P

REINFORCED CONCRETE FLAT PLATE SLAB FLOOR

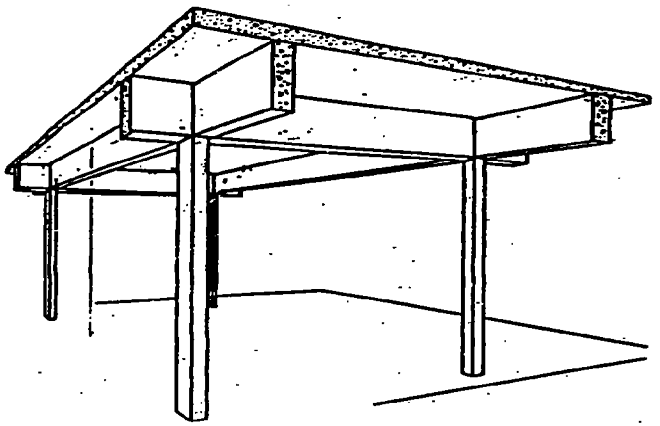


DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi		
	AS-BUILT	SHORED 1/3 span	SHORED 1/4 span
MEDIUM	2	NA	37
HEAVY	4	31	50

SHORING TYPE - P

Fig. V-29. Flat Slab and Flat Plate Floor Systems.

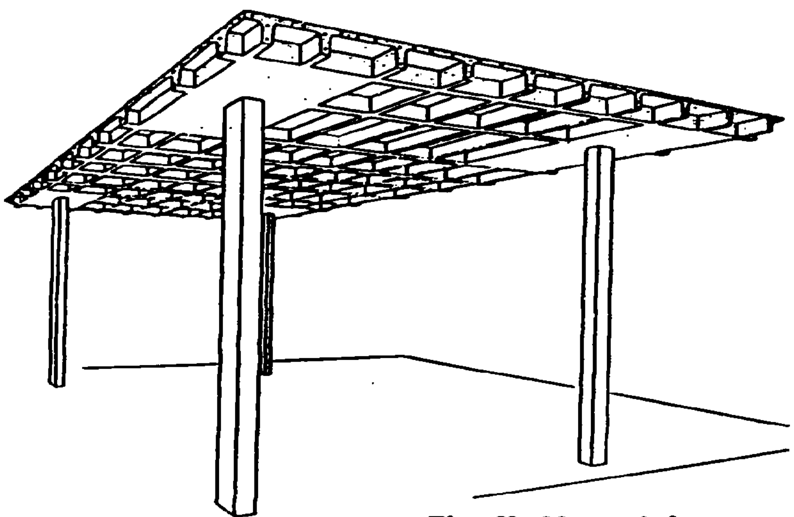
REINFORCED CONCRETE TWO-WAY SOLID SLAB FLOOR



DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi		
	AS-BUILT	SHORED 1/3 span	SHORED 1/4 span
MEDIUM	2	NA	37
HEAVY	4	31	50

SHORING TYPE - P

REINFORCED CONCRETE WAFFLE SLAB FLOOR



DESIGN OCCUPANCY LOADING	SURVIVAL OVERPRESSURE, psi		
	AS-BUILT	SHORED 1/3 span	SHORED 1/4 span
MEDIUM	2	NA	44
HEAVY	4	31	50

SHORING TYPE - P

Fig. V-30. Reinforced Concrete Two-Way and Waffle Slab Floors.

Table V-4

OCCUPANCIES FOR EACH LOAD GROUP

MEDIUM 80 to 125 psf	HEAVY 150 to 250 psf
Assembly Areas & Auditoriums w/Movable Seats & Stages	Armories
Dance Halls & Ballrooms	Manufacturing - Heavy
Dining Rooms & Restaurants	Storage - Heavy
Gymnasiums	
Libraries - Stackrooms	
Manufacturing - Light	
Office Buildings - Lobbies	
Printing Plants	
Skating Rinks	
Storage - Light	
Stores - Retail & Wholesale	

Shoring Methodology

Because of structural considerations, particular types of floor constructions must be shored only with certain shoring configurations. A floor construction defined as a one-way system, i.e., the principal structural reinforcement runs in one direction only, will require lines of shoring the full width of the bay, perpendicular to the direction of the principal reinforcement. Shoring of these types of construction is accomplished by using **POST & BEAM** shoring, and is appropriate for the following concrete floor systems:

PRECAST PRESTRESSED CONCRETE SINGLE & DOUBLE TEE FLOORS
PRECAST PRESTRESSED CONCRETE HOLLOW-CORE SLAB FLOORS
REINFORCED CONCRETE ONE-WAY JOIST FLOORS
REINFORCED CONCRETE ONE-WAY SOLID SLAB FLOORS

Each of the above floors has a **SHORING TYPE - P & B** indicated on Figures V-27 and V-28.

A two-way floor system, i.e., where the principal reinforcement in the concrete runs in two directions, normally perpendicular to each other, requires shoring symmetrically throughout the bay by individual posts. **POST** shoring is used for these types of construction and is appropriate for the following floor systems:

REINFORCED CONCRETE FLAT SLAB FLOOR
REINFORCED CONCRETE FLAT PLATE FLOOR
REINFORCED CONCRETE TWO-WAY SOLID SLAB FLOOR
REINFORCED CONCRETE WAFFLE SLAB FLOOR

Each of the above floors has a **SHORING TYPE - P** indicated on Figures V-29 and V-30.

Shoring Systems

For simplification, only specific sizes of timber shoring are presented for the two, POST & BEAM and POST, shoring configurations. Since the determination of the sizes of shoring members is based on a number of structural considerations, the use of the sizes indicated below are restricted to the following parameters:

1. The length of the span (beam to beam, beam to wall, or wall to wall) for one-way floor systems should not exceed 15 ft.

2. The dimensions of the bay, in either direction, for two-way floor systems should not exceed 24 ft.

3. For floor systems that require shoring at the 1/3 spans, the one-way floor systems should have the post & beam shoring spaced not over 5 ft on center the entire width of the shored area, and for the two-way floor system with the post shoring spaced symmetrically in each bay, the posts should be a maximum of 8 ft on center in either direction.

4. For floor systems that require shoring at the 1/4 spans (only two-way systems qualify), the post shoring should be located symmetrically in each bay with the posts a maximum of 6 ft on center in either direction.

5. The distance between the basement floor and the concrete members or slab above should not exceed 12 ft.

6. All shoring should be positioned as close to vertical as possible, and should be shimmed tightly between the floor and ceiling.

The sizes of the timber members required to accomplish the upgrading are as follows:

POST & BEAM SHORING
(for use in one-way floor systems)
BEAMS - 12 BY 12 IN. TIMBER
POSTS - 12 BY 12 IN. TIMBER

POST SHORING
(for use in two-way floor systems)
POSTS - 10 BY 10 IN. OR 11 IN. DIAMETER TIMBER

A shoring system, when constructed using the above indicated material sizes, and when installed in the manner and in the locations described above, will provide upgrading to the survival overpressure levels shown on Figures V-27 through V-30. When larger bay sizes or greater span lengths, or higher floor to ceiling heights, are encountered, shore spacing other than indicated and shoring materials different in size from those shown above, may be appropriate. In these special cases, however, the shoring systems will be required to be re-engineered.

Closures

In order to maintain the integrity of the shored protective space, as well as to protect the equipment from possible damage from debris and dust, openings such as stairwells, elevator and ventilating shafts, windows and doors should be closed off. Many types of materials, including timber beams and posts, steel plate, desk and table tops, and solid doors, may be used for this purpose, provided that these materials have the strength to survive the required blast overpressure loading. Chart 2 is provided herein to assist in determining the thickness of timber beams required, relative to the minimum span to be closed (always span the minimum span direction of the opening, if possible). This chart was calculated for both 30 and 50 psi, and is structurally compatible with the shoring systems described above for each of those particular survival overpressures. For overpressure values between 30 and 50 psi, the required timber thickness may be determined by interpolation.

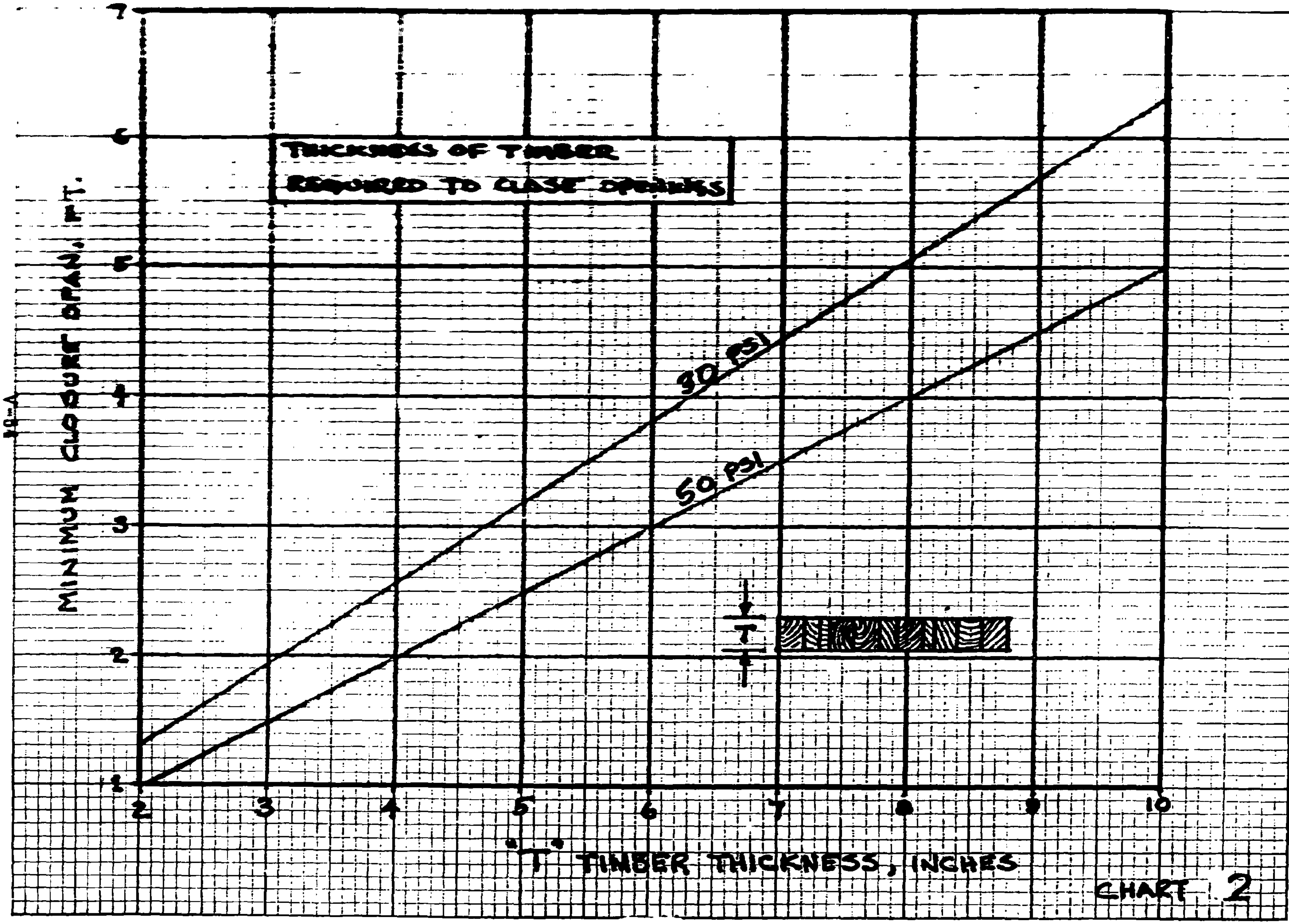

THICKNESS OF TIMBER
REQUIRED TO CLOSE OPENINGS
MINIMUM CLOSURE SPAN, FT.
1
2
3
4
5
6
7
2
3
4
5
6
7
8
9
10
30 PSI
50 PSI
T
"T" TIMBER THICKNESS, INCHES

CHART 2

Section 3
ATTACHMENTS

Attachment V-1
FIRE HAZARD

The thermal radiation released in a nuclear explosion is not considered in itself a direct hazard to industrial facilities. However, fires generated by the thermal radiation as well as blast induced fires may constitute a significant threat to equipment.

The magnitude of the fire hazard depends not only on the characteristics of the industrial plant itself as discussed earlier but also on the nature of the construction surrounding the plant. With, of course, some obvious exceptions industrial plants as a whole are quite fire resistant or at least can be made so. Structures are generally of non-combustible materials and unless the products of the plant are combustible there is little combustible material onsite to burn. However, if the plant is adjacent to heavily built up areas (e.g., multistory commercial) sufficient combustible debris may be blown into the plant area by the blast wave to cause a serious problem. The general nature of this problem is illustrated in Figure V-31. If it is desired to protect the plant to 10 psi then a check must be made to see if there are any densely built up areas within about 800 ft of the equipment. If so then the only countermeasures that can be used are burial and evacuation. Similarly for 20 psi the distance is about 1300 ft. For less densely built up areas such as residential the distances for a moderate fire hazard are less than 250 and 500 ft respectively.

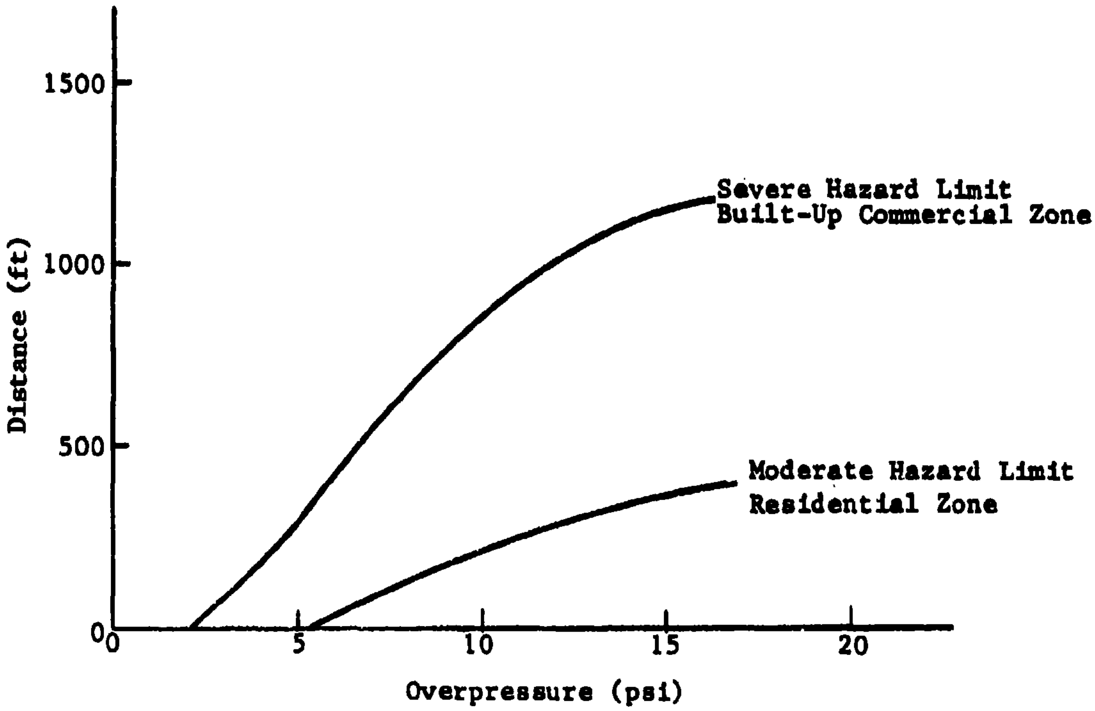


Fig. V-31. General Nature of Exterior Fire Hazard.

Attachment V-2
MISCELLANEOUS COUNTERMEASURES

1. SHUT DOWN OPERATIONS - many items of process equipment are much more sensitive to blast when in operation than when closed down - this includes, e.g., refineries and steel mills.

2. DISMANTLE AND BURY - applicable to structure like equipment, e.g., belt and roller conveyers and other stationary material handling equipment.

3. ADD WEIGHT - for example, fill empty tanks with water - will increase W/A considerably

4. SHIELDING/CLUSTERING - place small electronic items into a 50-gal drum half filled with sand, and place this drum in a cluster of drums.

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Attachment V-3

DISCUSSION OF EQUIPMENT WHOSE SURVIVABILITIES CANNOT BE CALCULATED BY THE STANDARD PROCEDURES

Category 1. Items of equipment which are really structures and are mounted to the ground surface or other massive surfaces in such a way that they cannot move as a single unit under the blast loading without causing serious damage to themselves. Equipment fitting in this category includes:

a. Tank structures

b. Box structures (material storage bins)

c. Large frame structures (conveyor belts or other stationary material transfer systems)

d. Exhaust stacks

Category 1 equipment is generally not going to be considered in the essential equipment category because there usually are alternative ways to accomplish the same operation or to jury rig make-shift equipment post attack to replace the damaged items. Because of the generally low survival rating of this type of equipment (2 to 5 psi) if any items are essential then it would be necessary to dismantle them and bury or evacuate the pieces. Guying is possible (e.g., exhaust stacks and water towers), but generally will not raise the survivability overpressures above 5 psi and requires "deadman" anchors that would need to be installed several weeks in advance.

Category 2. Equipment that is quite brittle such that even moderately small relative motions of its parts could cause serious damage. Sample types of equipment in this category would include:

a. Glass-lined tanks and pipes and other equipment containing glass, which would be severely damaged if the glass breaks

b. Refractory lined equipment such as boilers, furnaces, stacks to 30 ft, and small calciners

It is estimated that the survivability of the above types of equipment will range from about 0.5 to 0.75 that given by the standard procedure.

Category 3. Equipment items that are small such as electric motors, small hand and power tools. The prediction method will yield much too low survivabilities for these items. Any such small items that are truly essential, however, are readily evacuated, buried, or put in a cluster (see miscellaneous countermeasures, item 4). Small items of equipment required for recovery should be evacuated, rather than buried or left in a cluster, because they may be needed to recover just such protected items.

Attachment V-4
GLOSSARY

AIR BURST: The explosion of a nuclear weapon at such a height that the expanding fireball does not touch the earth's surface when the luminosity is a maximum (in the second pulse).

BLAST WAVE: A pulse of air in which the pressure increases sharply at the front, accompanied by winds, propagated from an explosion.

BURIAL: The protection of an item of equipment from the blast and thermal effects of nuclear weapons by burying it in the ground (or placing a mound of earth over the equipment).

CLUSTERING: The protection of an item of equipment from the blast effects (and to some extent the thermal effects) of nuclear weapons by clustering a number of items of equipment and securely fastening them together.

COUNTERMEASURES: Measures taken to protect equipment from the effects of nuclear weapons - primarily the blast effects.

DYNAMIC PRESSURE: The air pressure that results from the mass air flow (or wind) behind the shock front of a blast wave.

ELECTROMAGNETIC PULSE (EMP): A sharp pulse of radio-frequency (long wave length) electromagnetic radiation produced when an explosion occurs in an unsymmetrical environment, especially at or near the earth's surface or at high altitudes. The intense electrical and magnetic fields can damage unprotected electrical and electronic equipment over a large area.

ESSENTIAL EQUIPMENT: An item of equipment whose operation is necessary because no production could be accomplished without it. It is imperative that all essential equipment be protected as much as possible from the possibility of severe damage for the production process to resume post-attack.

EVACUATION: The movement of personnel and equipment from a risk area (where they are likely to be exposed to dangerous levels of nuclear weapons effects) to a safe area (where they would be exposed at most to moderate fallout levels).

FALLOUT: The process or phenomenon of the descent to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself.

HARDEN: An action taken to protect an item of equipment from the effects of nuclear weapons, i.e., to increase its survivability; generally used in relation to blast effects.

INITIAL NUCLEAR RADIATION: Nuclear radiation (essentially neutrons and gamma rays) emitted from the fireball and the cloud column during the first minute after a nuclear (or atomic) explosion.

ISOLATING: The process of hardening an item of equipment by moving it outside a building and away from other equipment and buildings to eliminate equipment to equipment and roof impact and to minimize wall fragment impact.

PROTECTIVE HOUSEKEEPING: A collection of countermeasures designed to minimize potentially hazardous missiles and damage to fragile equipment appendages, to reduce the possibilities of fires, and to protect electronic and electrical equipment from EMP.

REORIENTING: The process of hardening an item of equipment by turning it on its side - applicable to equipment whose height is greater than either of the other two dimensions.

REVETMENT (SANDBAG): An array of sandbags used to protect an item of equipment or a cluster of equipment items from blast effects.

SEVERE DAMAGE: The degree of damage such that the equipment cannot be used post-attack without a major repair job (which cannot be done in-house) and/or replacing major parts of the equipment (which are not stocked in-house and have long lead times even under pre-attack conditions.

SURFACE BURST: The explosion of a nuclear weapon at the surface of the land or water at a height above the surface less than the radius of the fire ball at maximum luminosity (in the second thermal pulse).

SURVIVABILITY: By the blast survivability is meant the threshold overpressure level at which severe damage to an item of equipment will start to occur.

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6. Russel, J.W., and E.N. York, **Expedient Industrial Protection Against Nuclear Attack,** The Boeing Company, Seattle, WA, March 1980.

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12. York, E.N. et al., **Industrial Plant Hardness-Phase II,** DNA 4549F, Boeing Aerospace Company, Seattle, WA, April 1978.

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APPENDIX A
CALCULATIONS AND REFERENCE MATERIAL

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APPENDIX A
CALCULATIONS AND REFERENCE MATERIAL
USED IN DERIVING PREDICTION METHODS

Section

Section A-1

TRANSLATION OF EQUIPMENT BY BLAST*

Assume impulsive loading

Thus $m\,dv = A\,C_d\,q\,dt$

where

- m = mass in (lb-sec^2)/ft
- v = velocity in ft/sec
- A = area expressed in ft^2
- C_d = drag coefficient
- t = time in seconds
- q = dynamic pressure in psi
- $I_q = \int q\,dt$ dynamic pressure impulse in psi sec
- D = depth of equipment normal to blast in ft
- ρ = equivalent density of equipment in lb/ft^3
- γ = ratio of density of equipment to that of steel (500 lb/ft^3)
- dv = small increment in velocity
- dt = small increment in time

or $v = (A\,C_d/m) \int q\,dt$

$v = (A\,C_d/m)\, I_q$

For units as given

$v = 144(A/m)\,C_d\, I_q$

Also $A/m = 32.2/D\rho$

and $A/m = 32.2/500D\gamma$

Equation (1): $v = (9.3\,C_d\, I_q)/D\gamma$

* This material is from Ref. A-1, page 184

Section A-2

DISTANCE TO STOP SLIDING OBJECT*

$F_R = m\,(dv/dt)$ where F_R = frictional force in lb.

m = mass in $(\mathrm{lb\text{-}sec}^2)/\mathrm{ft}$

v = velocity in ft/sec

t = time in sec.

x = stopping distance in ft.

w = weight in lb.

C_f = coefficient of friction

Assume F_R is a constant

so $v = (F_R\, t)/m$

and $x = (F_R\, t^2)/2\,m$

or $x = (v^2\, m)/2\,F_R$

or $x = (v^2\, w)/64.4\,F_R$

Now $F_R = C_f\, w$

Equation ②: $x = v^2/64.4\,C_f$

From "Translation of Equipment by Blast":

Eq 1 $v = (9.3C_d\, I_q)/DF$

so $x = (1.33\, I_q^2\, C_d^{\,2})/D^2F^2C_f$

Now assume $C_f = 0.5$ and $C_d = 1.0$

Equation ③: $x = (2.66\, I_q^2)/D^2F^2$

* This material is from Ref. A-1, page 155

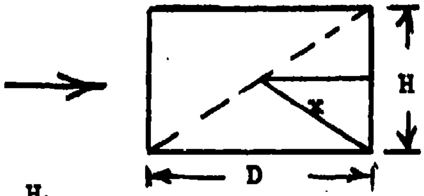
Section A-3, A-4

MINIMUM VELOCITY NECESSARY FOR OVERTURNING*

Assumes: Impulsive loading, worst case — with equipment accelerated to final velocity (the maximum) in a sliding mode, then hitting a surface discontinuity that stops the leading edge.

For overturning: Kinetic energy > Potential energy

direction of motion



$$K.E. = \frac{w v_o^2}{2g} > P.E. = w\left(x - \frac{H}{2}\right)$$

$f = D/H$

or $\quad v_o^2 > 2g\left(x - \frac{H}{2}\right)$

v_o = velocity in ft/sec

now $\quad x = \frac{(H^2 + D^2)^{1/2}}{2}$

w = weight in [illegible]

g = acceleration of gravity in ft/sec^2

or $\quad x = \frac{D}{2}\left(\frac{1}{f^2} + 1\right)^{1/2}$

thus $v_o^2 > g\,D\left[\left(\frac{1}{f^2} + 1\right)^{1/2} - \frac{1}{f}\right]$ or $v_o^2 > g\,D\left[\frac{(1 + f^2)^{1/2} - 1}{f}\right]$

Now assume f = 4 and term in brackets = 0.78

Equation ④: $\quad v_o > 5\,D^{1/2}$

Now velocity achieved from "Translation of Equipment by Blast" must be less than velocity necessary for overturning

thus $\quad v_a < v_o$

or $\quad (9.3 C_d I_q)/DF < 5\,D^{1/2}$ from Equations ① and ④

Equation ⑤ $\quad D > [(1.86 C_d\, I_q)/F]^{2/3}$

* This material is from Ref. A-1, page 156

Section A-5

SLIDING DISTANCE AT OVERTURNING THRESHOLD*

Now the sliding distance as derived earlier is

$$x = v^2/64.4C_f \qquad \text{(Eq 2)}$$

Applying the v_o value from Eq 4 at overturning:

$$x = 0.388D/C_f$$

with $C_f = 0.5$ as before

Equation 6 $\qquad x = 0.78D$

* This material is from Ref. A-1, page 156

Section A-6

RELATION BETWEEN DYNAMIC PRESSURE IMPULSE AND PEAK OVERPRESSURE

Assumptions:

1. The height of burst used is such as to maximize 20 psi.

2. The dynamic pressure impulse (I_q) is given by $0.28 q_o T_q$ where q_o is the peak dynamic pressure and T_q is the positive phase duration of the dynamic pressure. The .28 factor is suggested in Ref. A-2 for q_o values less than 10 psi.

Calculation:

The scaled distance from ground zero at which various pressure values are obtained was first determined from Figs. 3.73b and 3.73c of Ref A-3. The q_o values were then obtained from Fig. 3.75 of Ref. A-3 and the T_q values from Fig. 3.76. Finally the I_q values were computed from the equation given in (2) above. The T_q values are functions of the weapon yield so the I_q values are also. Values are given for weapon yields of 1 Mt and 0.1 Mt.

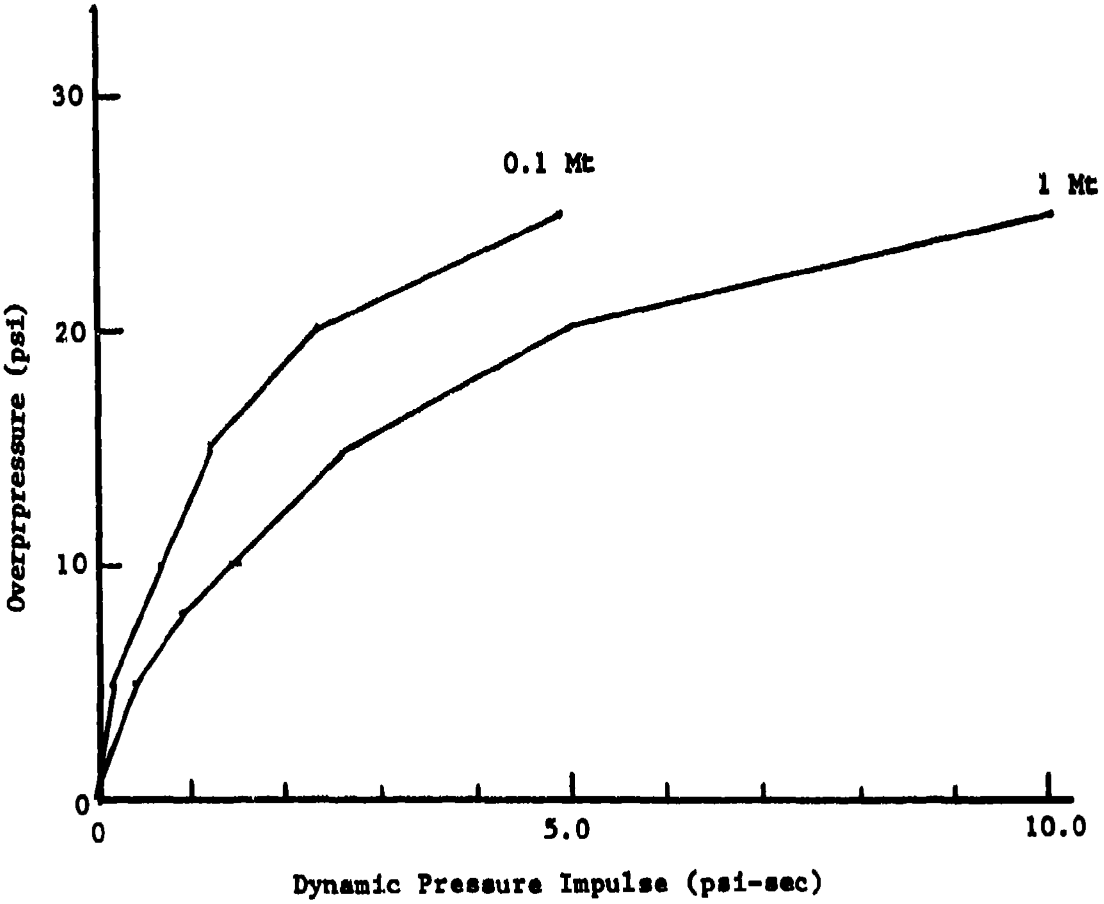


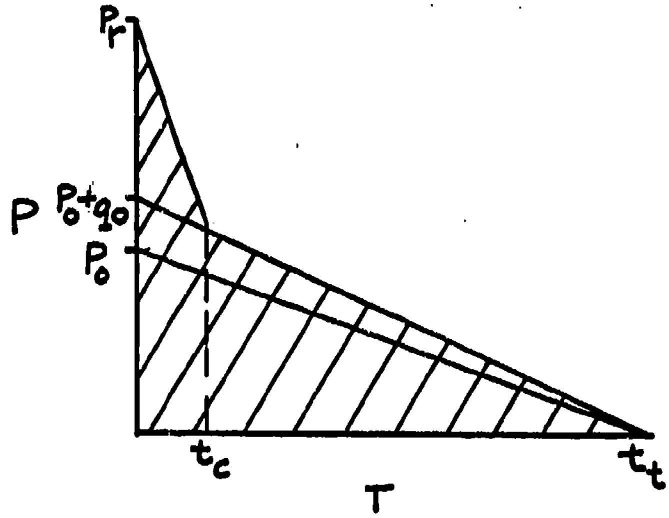
Fig. A-1. Overpressure vs Dynamic Pressure Impulse for Two Weapon Yields and an HOB to maximize 20 psi.

Section A-7*

WALL FRAGMENT VELOCITY FROM BLAST LOADING OF EXTERIOR FRANGIBLE WALL PANELS

CONSIDERATION OF BUILDING LOADING

It is generally assumed that the average front face loading on a building is as shown below:



where P_r = peak reflected pressure
P_o = peak incident pressure
q_o = peak dynamic pressure
t_t = effective triangular pulse duration
t_c = clearing time for the front face

at $t = 0$ loading is P_r
$t = t_c$ loading is the sum of $p + q$
$t = t_t$ loading is 0
where p = the overpressure at the appropriate time
q = the dynamic pressure at the appropriate time

* The material in Section A-7 is from Ref. A-4.

CONSIDERATION OF WALL PANEL LOADING

The actual loading on an individual frangible wall panel on the front face of a building can initially be approximated by that described above for the building, but as the wall panel starts to break up, the loading will be reduced until it reaches pure drag phase loading, i.e., q. For the range of pressures of interest the drag loading is so much smaller than the diffraction phase loading that it can generally be ignored.

The manner in which the loading changes is very complicated: it depends on a number of factors including the manner in which the panel breaks up, which in turn depends on the type of panel and its mounting; it depends on the location of the panel in the face of the building and on what types of wall panels surround it; and it depends on the panel and building sizes.

To get some reasonable estimate of the criteria to use for establishing the end of the diffraction phase loading on the wall panel, it is helpful to consider several limiting cases.

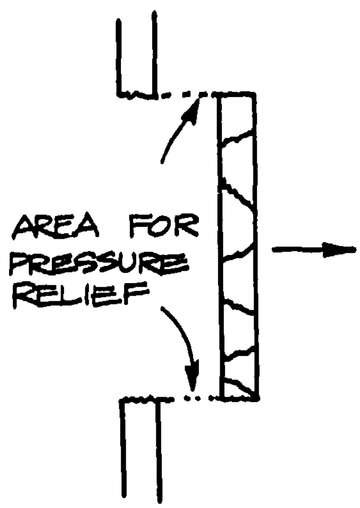
First, we will consider the case of a simple beam mounted wall with supports top and bottom. From Ref. A-5 it is shown that such a wall panel cracks along the horizontal center line with each piece initially tending to rotate about its support and opening up a horizontal gap in the center of the panel. This is perfectly analogous to the opening space of a double doorway, as both doors are pushed outward. As shown in Calculation D-1 for such a geometry, when the middle of the panel has moved a distance of 25% of the wall height, the open area (doorway opening) in the gap is some 13% of the total panel (plus open) area; and when it has moved a distance of 37.5% of the wall height, the open area is some 34% of the total area.

Now in order to evaluate the load on the "swung-open" wall panel at the instant when the opening is equal to a given percent of the panel area, it is assumed that this load is equal to the load felt by an undamaged wall panel having a door or window opening equal to the cracked opening percentage. The loading study data given in the same reference show that the net loading on a wall with an opening of

15% of the wall area is from 60% to 75% of that for a solid wall depending on whether the opening is in the shape of a window in the middle of the wall or a door at the edge of the wall. Further, they show that, when the opening is 34% of the total area, the loading has reduced to about 30% for the case of the window geometry.

Since there is still a significant loading for the 25% wall height travel distance (roughly 2/3) and relatively little for the 37.5% distance (roughly 1/3), it seems reasonable to approximate the actual loading by a steady state loading equal to the initial value up to about a 30% wall height travel distance and then to assume the loading drops to zero.

Another limiting case of concern is where essentially the entire panel punches out and moves more or less as one piece even though fragmented. This could occur, for example, with a fixed beam mounting where the maximum stress occurs initially near the edges of the panel rather than in the middle as for the simple beam. For this geometry several subcases are of interest. First, consider the situation where there are floors above and below the panel so the pressure relief can only come from the sides as indicated in sketch A, a plan view of the wall. As shown in Calculation D-2 for this geometry, when the wall has moved a distance of 25% of its height the open area is 18% of the total and for a distance of 37.5% the open area is 28%. These values do not differ greatly from those for the previous case so that again it seems reasonable to select a 30% wall height travel distance as the termination of the loading.

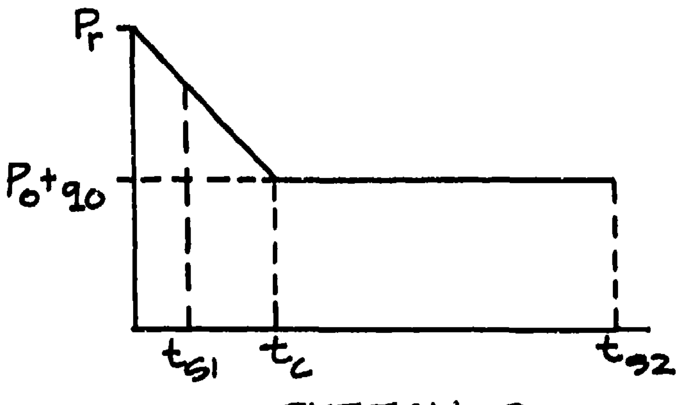


SKETCH A

If there were no floors, the travel distance should be somewhat less because there is pressure relief top and bottom as well as on the side. However, if there are other similar wall panels surrounding the panel of concern, then the travel distance would likely be greater because these other panels would reduce the pressure relief.

One other method of pressure relief is by fragmenting of the walls combined with a range in velocities of fragments, which is only reasonable to expect. Consider, for example, a wall of thickness x, which travels, on the average, a distance of 4x in a time t. If some fragments are traveling 25% faster than the average and some 25% slower, then there will be a space of one wall thickness between the trailing edge of the faster fragment and the leading edge of the slower fragment, giving significant potential for blast leakage. To compare these results with those above, assume a typical wall thickness and height, say 8 in. and 8 ft respectively. This gives 2.4 ft from the 30% wall height travel distance and 2.6 ft from the 4 wall thickness distance. The value of 2.4 ft was used for comparison against a scale model test of 9 in. brick walls. These results, which are discussed in more detail later, show that in all cases the calculated velocities were higher than the measured ones. For the shock tunnel tests the experimental values were from about 70% to 75% of the calculated ones, while in the scale model brick wall tests the measured values ranged from about 80% to 90%. For this reason it seems desirable to empirically adjust the 2.4 ft value enough to reduce the velocity values by 20%. This results in a value of 1.5 ft, which will be used in the final calculations.

As will become evident later in the discussion, the times for the wall panels to travel this distance are very short compared to the pulse durations, so that both p and q can be considered to remain constant during this time. Thus, the loading pulse of concern is shown in sketch B.



SKETCH B

For this type of pulse, a convenient lower limit to the loading can be obtained by ignoring the reflected pressure spike and using a flat-topped loading of $p = p_o + q_o$. Similarly, a convenient upper limit can be established by using a flat-topped loading of $p = p_r$. The first case corresponds most closely to that for a very small building where the time available for the missiles to accelerate, t_{s2}, is much larger than t_c; while the second corresponds to a very large building where t_{s1} is significantly less than t_c. All actual buildings will fall between these two limits. As will be shown later velocities computed for these two limits do not differ greatly, and an average value can be used with an uncertainty of $\pm$ 20%, which covers both limits. Thus, at the present time, it does not seem warranted to include the complexities of building size in the evaluational procedure.

CALCULATION OF MISSILE VELOCITIES

$$F = PA = M(dv/dt)$$

for P constant $\quad v = (A/M)Pt$

and $\quad x = (A/M)(Pt^2/2)$

or $\quad t = (2Mx/AP)^{\frac{1}{2}}$

and $\quad v = (2APx/M)^{\frac{1}{2}}$

Now for

v in ft/s
P in $lb/in.^2$
A/M in $ft^3/lb\text{-}s^2$
x in ft

$$v = 12(2APx/M)^{\frac{1}{2}}$$

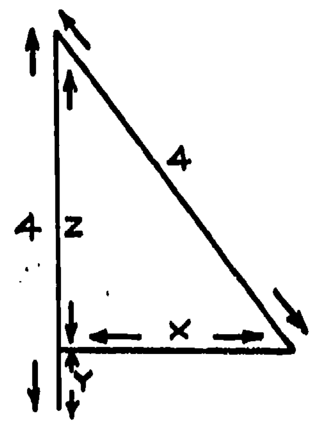
and for

x = 1.5 ft - the assumed travel distance
$v = 20.8(AP/M)^{\frac{1}{2}}$
$t = 0.14(M/AP)^{\frac{1}{2}}$

CALCULATION D-1

x = horizontal travel distance

4 ft = wall 1/2 height



f = fraction open area $= y/4 = 4\text{-}z/4$

and $z = (4^2 - x^2)^{\frac{1}{2}}$

so $f = 1 - (1-x^2/4^2)^{\frac{1}{2}}$

x (ft)	f (%)
1	0.03
2	0.13
2.5	0.22
3	0.34

CALCULATION D-2

PLAN VIEW

horizontal travel distance = x

wall thickness = 2/3 ft

wall height = H = 8 ft

wall length = L = 12 ft

fraction open area = f = $2x'/(12 + 2x')$

and x' = $x - 0.67$

so f = $2(x - 0.67) / 12+2(x-0.67)$

x (ft)	f (%)
1	0.05
2	0.18
2.5	0.23
3	0.28

COMPARISON OF PREDICTIONS WITH EXISTING FRANGIBLE PANEL DATA

Both full-scale and model experimental data are available to check the prediction methods. These are from:

1. Tests conducted in the Shock Tunnel Facility of [illegible] ft x [illegible] ft concrete block, clay tile, and sheetrock walls (Ref A-[illegible]).

2. Tests of model scale brick walls exposed to the blast from an explosion of [illegible] tons of TNT ([illegible] kt nuclear equivalent)(Ref A-[illegible]). The brick walls being modeled were [illegible] in. thick, [illegible] ft high, and [illegible] ft wide. Two scales were used, 1/[illegible] and 1/[illegible], and two pressure levels, [illegible] and [illegible] psi. The walls were clamped on all four sides in a rigid frame so that arching would be expected. The authors estimated that the pressure level of [illegible] psi was just slightly above the failure level, and in fact one of the 1/40 scale models did not fail but only cracked.

The results of the comparisons are shown below:

Shock Tunnel Comparisons

Wall Type	W/A (psf)	P(r) (psi)	Velocity (ft/sec) Pred Method A	Pred Method B	Shock Tunnel Report Calc	Shock Tunnel Report Meas
[illegible] in CM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] [illegible]
[illegible] in CT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SH Rock	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] [illegible]
"	"	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] [illegible]

[illegible] Brick Wall Comparisons

Overpressure (psi)	Scale	Measured Velocity(1) (ft/sec)		Calculated Velocity (ft/sec)	
		Mean	Range	Pred Method A	Pred Method B
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(1) The measured velocities are for the two larger fragment groups generated in the wall breakup, as they were deemed the most important.

Note that the prediction method requires selection of a travel distance during which essentially the full peak reflected or stagnation pressure is applied to the wall fragment. For the initial set of the problem a distance of [illegible] ft was selected. These are the velocities given under Pred Method A. It was evident that these numbers were on the high side of the experimental values although not all that different from the [illegible] calculations. To get closer agreement with the experimental data the travel distance was reduced to 1.0 ft which in turn reduced the velocities by about [illegible]. These are the velocities given under Pred Method B. It can be seen that the Pred Method B values are within 10% to [illegible] of the measured values as well as the [illegible] calculations.

Section A-8

EFFECTIVE IMPACT VELOCITY OF FRANGIBLE WALL FRAGMENTS

If a non-rigid frangible wall impacts a piece of moderately heavy equipment there would seem to be a good chance that the equipment will punch through the wall and that the effects of the impact will be much less severe than if the wall had been rigid. It is proposed here that the effective impact velocity (V_e) can be taken as the velocity of the body after being impacted by the wall. Assuming an inelastic collision, this can be calculated on the basis of conservation of momentum, i.e.,

$$V_e/V_w = W_w/(W_e)$$

where V_e is the velocity of the equipment after impact by the wall

V_w is the initial wall velocity

W_w is the weight of the portion of the wall that punches out and goes with the equipment

W_e is the weight of the equipment plus W_w

The approach used follows that given in Ref. A-4.

Section A-9

DEAD WEIGHTS OF TYPICAL INDUSTRIAL ROOF SYSTEMS

The attached calculations of the dead weight of selected roof systems used the weights from the attached Table A-1 and the applicable product brochures (Refs. A-7 through A-14).

Each roof system is designed to support a superimposed live load of 20 psf - a typical live load in areas where significant snow loads do not occur. The systems--the member sizes, spacing, spans, etc.--are designed in accordance with the 1985 Uniform Building Code, where applicable, and using sound engineering principles when the code is not specific.

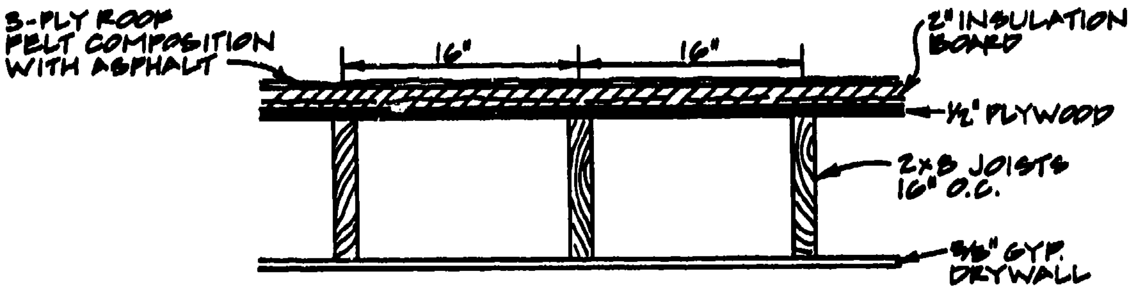
Assumptions

- Timber is Douglas Fir @ 32 pcf, construction grade F_b = 1200.
- Concrete is normal weight (hard rock agg.) = 150 pcf (except insulating concrete, see Table A-1).

Note: many times these roof constructions have mechanical systems in plenum, and designers will add 5 psf to system to accommodate.

Example 1

Sawn timber joist flat roof with insulation board built-up roof, plywood deck, gypsum drywall ceiling; 15-ft joist span.



Dead Weight

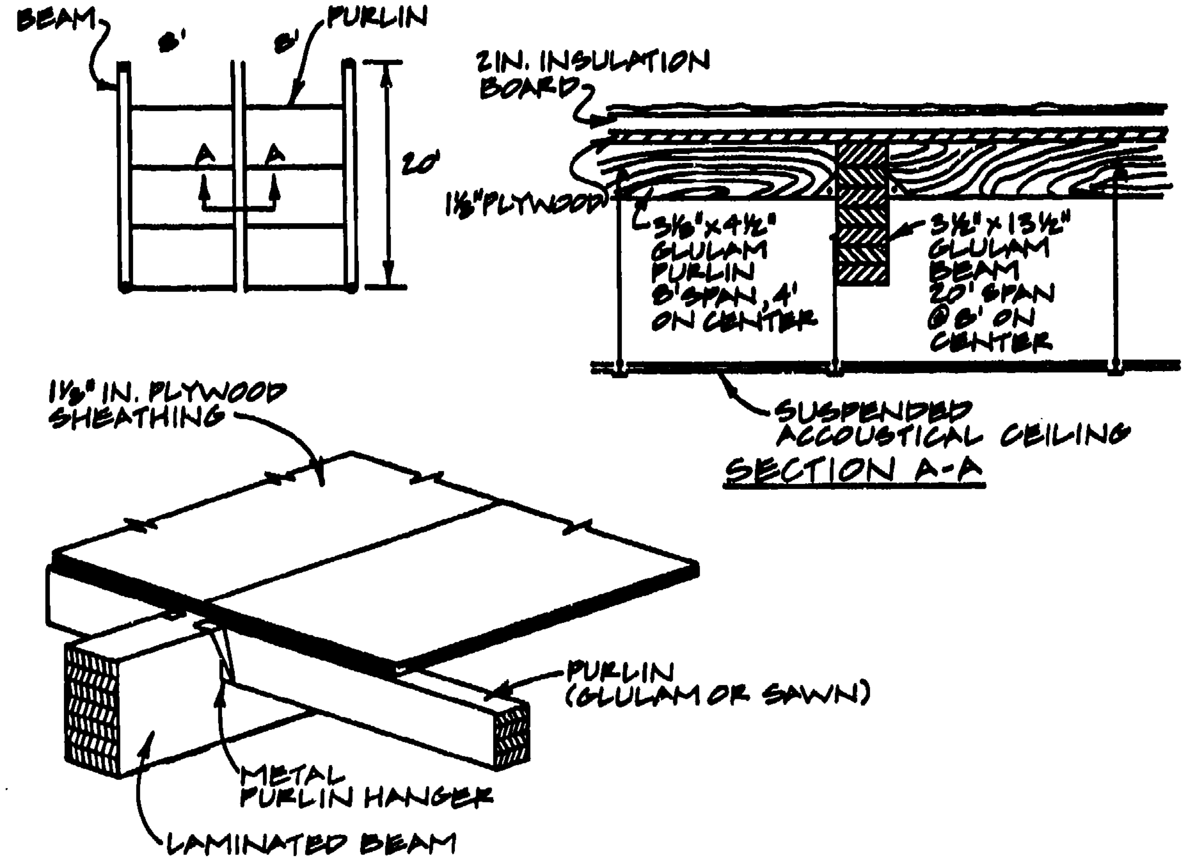
1. Joists = 1.5 x 7.5/144 x 32 = 2.5 x 12/16 = 2 psf
2. Plywood = 1/2-in. thick = 2 psf
3. Gypsum drywall = 5/8-in. thick = 2.5 psf
4. Insulation board - 2-in. thick = 1 psf
5. Three-ply built-up composite roof with asphalt = 3 psf

Total dead weight = 10.5 psf

Ref. A-7; Table A-1

Example 2

Flat roof with glulam beams and purlins, plywood deck, insulation board, built-up roof, suspended acoustical ceiling, 20 ft by 8 ft bay.



Dead Weight

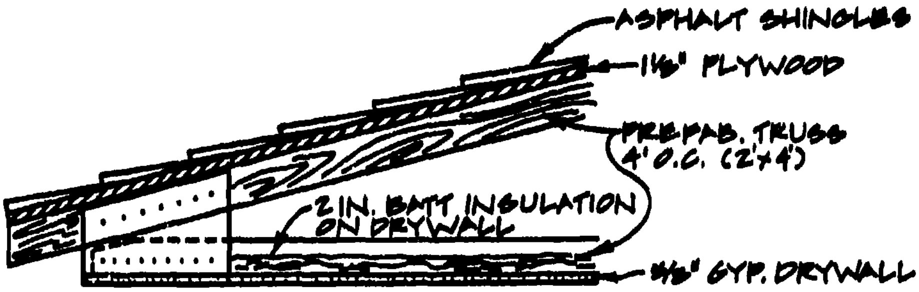
1.	Glulam beam = 3.5 x 13.5/144 x 35 = 11.5/8 =	1.5 psf
2.	Glulam purlins = 3.125 x 4.5/144 x 35 = 3.4/4 =	1 psf
3.	Plywood 1-1/8 in. thick =	4 psf
4.	Insulation board - 2-in. thick =	1 psf
5.	Acoustical ceiling =	2 psf
6.	Three-ply built-up composite roofing with asphalt=	3 psf

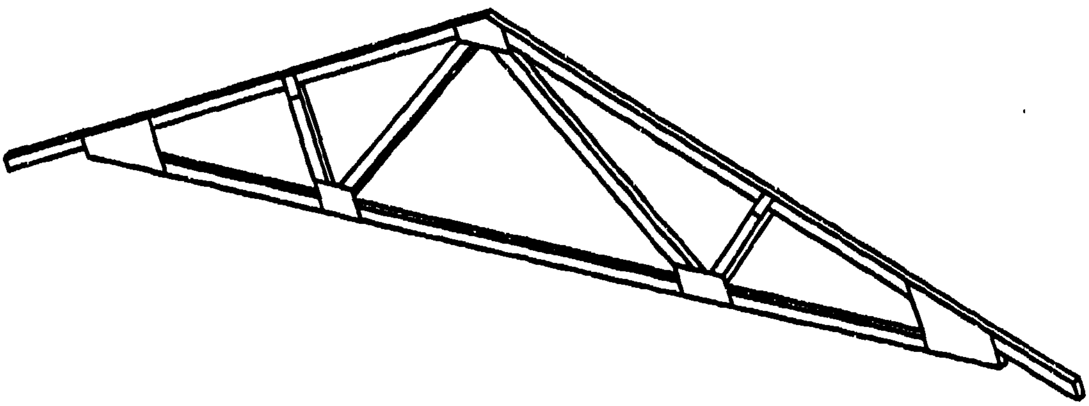
	Total dead weight =	12.5 psf

Ref. A-8, Table A-1

Example 3

Prefabricated, gabled roof trusses, 4 ft on center, plywood sheathing, shingle roofing, 5/8-in. gypsum drywall ceiling, batt insulation on ceiling. 16-ft span.





VIEW OF ONE PREFAB TRUSS

Dead Weight

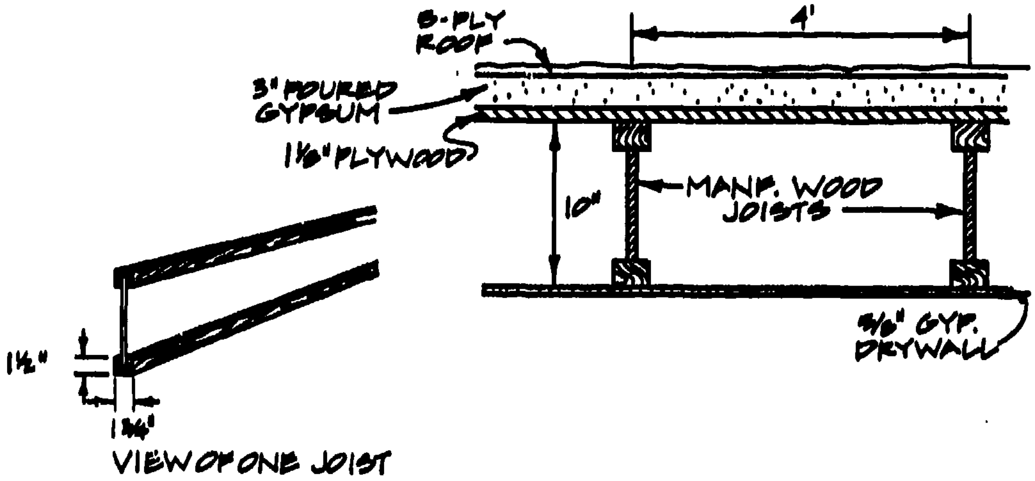
1.	Gable roof truss = 1.5x3.5/144x32 = 1.17x44 lf = 51/16x4 =	1 psf
2.	Plywood = 1-1/8-in. thick =	4 psf
3.	Roofing shingles =	3 psf
4.	Batt insulation, 2 in. =	1 psf
5.	Gypsum drywall, 5/8-in. =	2.5 psf

	Total dead weight =	11.5 psf

Ref. A-7, A-9, Table A-1

Example 4

Manufactured wood roof joists, 20-ft span @ 4 ft on center, plywood deck, 3-in. poured gypsum insulation, 5-ply built-up roof, 5/8-in. gypsum drywall ceiling.



Dead Weight

1. Manufactured wood joists = 2*lb/ft/4 = 0.5 psf
2. Plywood = 1-1/8-in. thick = 4.0 psf
3. Gypsum drywall = 5/8-in. thick = 2.5 psf
4. Poured gypsum insulation, 3 in. = 4 x 3 = 12.0 psf
5. Five-ply built-up composition roof = 4.0 psf

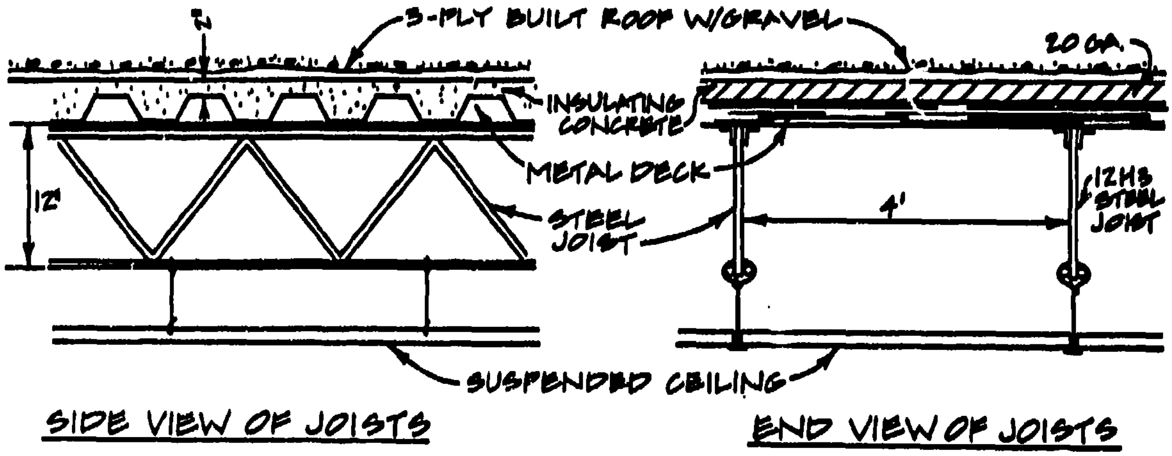
Total dead weight = 23.0 psf

* from brochure

Ref. A-7, A-10, Table A-1

Example 5

Open-web steel joist roof, joists 4 ft on center, metal roof deck, poured insulating concrete, 3-ply built-up roof with gravel, suspended acoustical ceiling.



Dead Weight

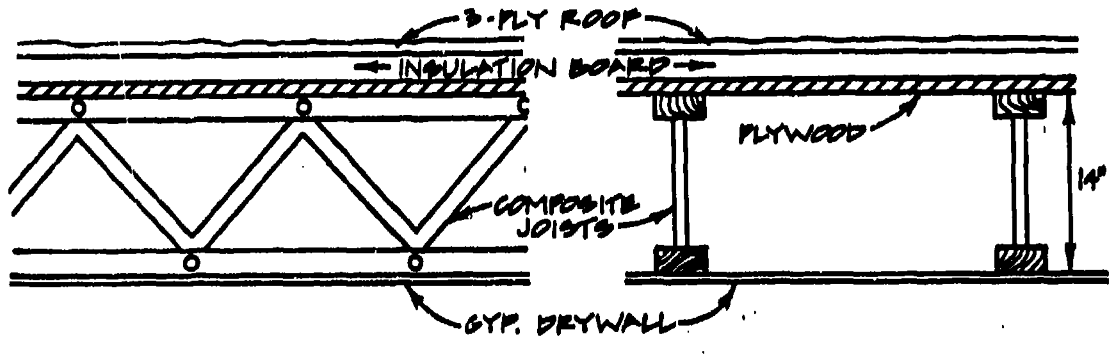
1.	Open-web steel joists = 5.2 plf/4 =	1.3 psf
2.	Metal roof deck, 20 ga = 2.1 psf =	2.1 psf
3.	Insulating concrete = 50 pcf 2+4/2 = 3/12 x 50 =	12.5 psf
4.	Suspended acoustical ceiling =	2.0 psf
5.	Three-ply built-up roof with gravel =	5.5 psf

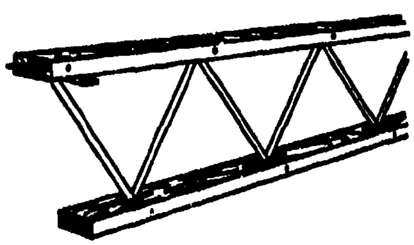
	Total dead weight =	23.4 psf

Ref. A-11, A-12, Table A-1

Example 6

Manufactured composite wood/steel joists, 4 ft on center, span 20 ft, 1-1/8 plywood sheathing, 2-in. insulation board, 3-ply built-up composite roof, 5/8-in. gypsum drywall ceiling.





VIEW OF ONE JOIST

Dead Weight

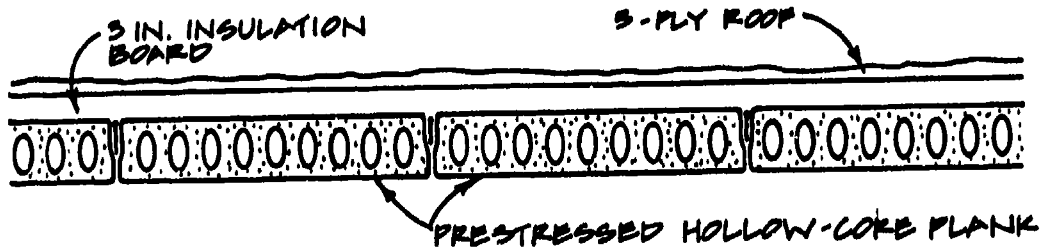
1.	Manufactured wood/steel joists = 3 plf/4 =	1 psf
2.	Plywood = 1-1/8-in. thick =	4 psf
3.	Three-ply built-up roof =	3 psf
4.	Insulation board - 2-in. thick =	1 psf
5.	Gypsum drywall 5/8 in. =	2.5 psf

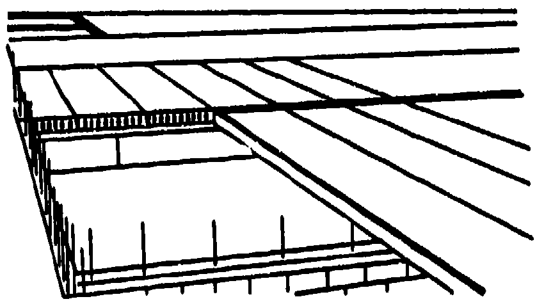
	Total dead weight =	11.5 psf

Ref. A-10, Table A-1

Example 7

Precast prestressed concrete hollow-core plank, 20 ft span, 3-in. insulation board, 5-ply roof, exposed ceiling.





DECK PARTIALLY IN PLACE

Dead Weight

1.	Precast prestressed plank =	35 psf
2.	Insulation board, 3-in. thick =	1.5 psf
3.	Five-ply built-up roof =	4.0 psf

	Total dead weight =	40.5 psf

Ref. A-13, A-14, Table A-1

TABLE A-1: DESIGN INFORMATION

11.1.1 Dead weights of floors, ceilings, roofs, and walls

Floorings	Weight (psf)
Normal weight concrete topping, per inch of thickness	12
Sand-lightweight (120 pcf) concrete topping, per inch	10
Lightweight (90-100 pcf) concrete topping, per inch	8
7/8" hardwood floor on sleepers clipped to concrete without fill	5
1 1/2" terrazzo floor finish directly on slab	19
1 1/2" terrazzo floor finish on 1" mortar bed	30
1" terrazzo finish on 2" concrete bed	38
3/4" ceramic or quarry tile on 1/2" mortar bed	16
3/4" ceramic or quarry tile on 1" mortar bed	22
1/4" linoleum or asphalt tile directly on concrete	1
1/4" linoleum or asphalt tile on 1" mortar bed	12
3/4" mastic floor	9
Hardwood flooring, 7/3" thick	4
Subflooring (soft wood), 3/4" thick	2 1/2
Asphaltic concrete, 1 1/2" thick	18
Ceilings	
1/2" gypsum board	2
5/8" gypsum board	2 1/2
3/4" plaster directly on concrete	5
3/4" plaster on metal lath furring	8
Suspended ceilings	2
Acoustical tile	1
Acoustical tile on wood furring strips	3
Roofs	
Ballasted inverted membrane	16
Five-ply felt and gravel (or slag)	6 1/2
Three-ply felt and gravel (or slag)	5 1/2
Five-ply felt composition roof, no gravel	4
Three-ply felt composition roof, no gravel	3
Asphalt strip shingles	3
Rigid insulation, per inch	1/2
Gypsum, per inch of thickness	4
Insulating concrete, per inch	3

Walls	Un-Plastered	One side Plastered	Both sides Plastered
4" brick wall	40	45	50
8" brick wall	80	85	90
12" brick wall	120	125	130
4" hollow normal weight concrete block	28	33	38
6" hollow normal weight concrete block	36	41	46
8" hollow normal weight concrete block	51	56	61
12" hollow normal weight concrete block	59	64	69
4" hollow lightweight block or tile	19	24	29
6" hollow lightweight block or tile	22	27	32
8" hollow lightweight block or tile	33	38	43
12" hollow lightweight block or tile	44	49	54
4" brick 4" hollow normal weight block backing	68	73	78
4" brick 8" hollow normal weight block backing	91	96	101
4" brick 12" hollow normal weight block backing	119	124	129
4" brick 4" hollow lightweight block or tile backing	59	64	69
4" brick 8" hollow lightweight block or tile backing	73	78	83
4" brick 12" hollow lightweight block or tile backing	84	89	94
4" brick, steel or wood studs, 5/8" gypsum board	43		
Windows, glass, frame and sash	8		
4" stone	55		
Steel or wood studs, lath, 3/4" plaster	18		
Steel or wood studs, 5/8" gypsum board each side	6		
Steel or wood studs, 2 layers 1/2" gypsum board each side	9		

Section A-10
FIRE DAMAGE TO INDUSTRIAL EQUIPMENT

EXTERNAL FIRE HAZARD

Table A-2 summarizes data in the literature on the external fire hazard to industrial equipment. To illustrate the application of these data, consider the example of an industrial plant that is adjacent to a built-up commercial area exposed to a blast overpressure of 10 psi. For this condition the external fire hazard as indicated by the table is "severe within 900 ft". The implication is that:

1. Combustible debris from the commercial areas will be blown for distances up to 900 ft in the direction of the blast wave.

2. There is sufficient fuel loading in this structural debris to cause a severe fire hazard to exposed equipment. Severe is defined in the notes to the table as a fuel loading of 6 to 30 lb per sq ft.

3. There is a high probability of fire in the area.

Thus, if the commercial area lies between the likely ground zero of the weapon and the industrial plant, and is separated from the plant by a distance of approximately 200 ft, then a 700-ft downwind segment of the plant would be subjected to a severe fire hazard **purely from external sources.**

Based on the work of Martin (Ref. A-15), the debris and fire characteristics of typical residential and commercial areas are as follows:

Residential area at 5 psi (building density = 0.2): Nearly all wood frame and masonry buildings collapsed, with structural debris near the site covering an area at most about twice the building plan area. Lighter debris (building contents) spread over space between buildings. Average debris displacement 60 to 70 ft and maximum range 100 to 140 ft. Initial fire density low, with one debris fire out of 100 to 500 structures, and little chance of fire spread because of discontinuous nature of fuel distribution.

Table A 2

EXTERNAL FIRE HAZARD TO EXPOSED INDUSTRIAL EQUIPMENT

Blast Overpressure (psi)	Urban Land Use of Adjacent Area: Residential	Urban Land Use of Adjacent Area: Built-Up Commercial
2	none	none
5	none	Severe within 300 ft
10	Moderate within 250 ft	Severe within 900 ft
15	Moderate within 400 ft	Severe within 1,200 ft

Notes:

Residential area is assumed to have 0.2 building density with 20 ft structure height.

Built-up commercial area is assumed to have about 0.5 building density with heights varying from 70 to 200 ft.

Moderate hazard is defined as exposure to fire from fuel loadings of 1.5 to 3.0 lb/sq ft of surface area.

Severe hazard is defined as exposure to fire from fuel loadings of 6 to 30 lb/sq ft of surface area.

Exposed equipment includes:

Equipment in the open;

Equipment in buildings that would be collapsed by the blast wave;

Equipment on the ground floor of buildings whose walls would be largely removed by the blast.

Because only lightweight building contents are translated to any significant distance, this situation does not constitute any significant hazard to an adjacent industrial plant.

Residential area at 10 psi: Total debris (structural and building contents) more or less uniformly spread over entire area except for large open areas such as parks. Average debris displacement 0 to 165 ft, and maximum range, 300 to 500 ft. Average debris depth 1/2 to 1 ft. Fire incidence quite high throughout the more or less uniformly spread debris. Fuel loading = 1.5 to 3 lb per sq ft. Burning time maximum of 30 minutes.

For this case the debris fires will extend at least 150 to 165 ft and no more than 300 to 360 ft from the edge of the residential area. Taking the midpoint between these two distances (250 ft) as a somewhat arbitrary cutoff, we can say that equipment within 250 ft of the edge of a residential neighborhood will be exposed to fires from fuel loadings of 1.5 to 3 lb per sq ft, with burning times up to 30 minutes.

Residential area at 15 psi: The situation is generally similar to that at 10 psi, except the cutoff distance, calculated as above, is 410 ft.

Built-up commercial area at 5 psi (building density = 0.5): Region of moderate damage to typical structures. Partial collapse of some structures. Debris tends to cover most of the available space. Depths range from 4 to 11 ft with high combustible content. Mean displacements are 100 to 300 ft with maximum range 200 to 300 ft. Moderate number of initial fires (mean distance between fires on the order of 300 ft). If no self-help firefighting within 20 minutes, one large mass fire will develop in an hour.

Because of much greater depth of debris, 4 to 20 times that for residential areas, it is felt that significant debris will exist near the limit of range so that cutoff is selected as 300 ft. No estimates of actual fuel loading are given by Martin, but, based on debris depths, it can be estimated as 5 to 10 times greater than for residential--or some 6 to 30 lb per sq ft.

Built-up commercial at 10 psi: Situation somewhat similar to 5 psi except for more structures collapsed with somewhat thicker debris (4 to 15 ft). Mean

displacement is 200 to 500 sq ft with maximum range 500 to 1,000 ft. High initial fire incidence leading to mass fire--burn duration in terms of hours.

Cutoff selected as 900 ft and severe damage assumed within this distance from edge of built-up commercial area.

Built-up commercial at 15 psi: Most structures totally collapsed. Debris tends to cover most of available area to a depth of 6 to 22 ft. Mean displacement is 300 to 660 ft and maximum range is 750 to 1,400 ft.

Cutoff distance selected as 1,200 ft and severe damage assumed within this distance.

INTERNAL FIRE HAZARD

The types of plants that have a potential internal fire hazard include:

A. Plants processing solid combustible materials.

B. Plants processing liquid combustible materials.

C. Other plants that, for one reason or another, have large quantities of combustible materials onsite. These include, for example, plants in which a large number of wooden structures are onsite.

Type A Plants

With proper protective housekeeping it is believed that these types of plants can be made to have fewer ignitions than would occur in a typical residential area. Thus, at the 5 psi level no significant fire hazard exists since for residential areas there is a low probability of fire incidence--less than one per hundred structures.

At the 10 psi level in residential areas, there is a high probability of fire ignition. For these types of industrial plants the ignitions prior to blast wave arrival would be much fewer and possibly negligible. However, keeping in mind that: (1) the blast wave will likely blow out walls and distribute the combustible material throughout the plant area; and (2) there is sufficient thermal radiation arriving after

the blast to ignite kindling fuels, it would appear that a significant fire hazard is likely to exist at 10 psi.

The severity of the fire hazard will depend on how much combustible material is onsite. An estimate of this can be made by distributing the total combustible material over the total plant area. If the resultant fuel loading is similar to that for a typical residential area (see Table A-2), the hazard is considerate moderate, while if it approaches that of typical built-up areas, it would be severe.

Type B Plants

It is very difficult to generalize about the potential internal fire hazard in plants processing liquid combustible materials. Such plants typically have very little other combustible material onsite, and such buildings as exist would be mode of non-combustible materials. The key factor here is whether and how the blast effects release significant quantities of the combustible material. It would seem safe to assume that the released materials will encounter an ignition source and, if permitted to spread throughout the plant, would cause great damage to equipment.

It would seem very critical whether the plant is in an operating or shutdown mode. In the shutdown mode, it would seem reasonable to assume that the combustible material would be in tanks in storage areas, which are typically surrounded by dikes to contain the material in the case of an accidental spill under normal conditions. If this spill volume is sufficient to contain all the combustible fluids, then it is reasonable to say that the shutdown plant will have no internal fire hazard except, of course, in the storage tank area. It should be noted, however, that the diked volume may not be sufficient if there are a large number of tanks, since under normal conditions, it would not be considered reasonable for two or more tanks to spill simultaneously. Thus, with an inadequate spill volume a severe fire hazard could exist in other parts of the plant depending on the surface geometry.

In the operating mode, it seems possible that the plant could experience a serious fire hazard at overpressures below those which would destroy the plant by blast alone. This, of course, depends on the specific plant layout and the types and quantities of the liquid combustible materials being processed, so that no generalized overpressures can be quoted. In the case of one refinery studied, however, it is interesting to note that in the shutdown mode it was capable of withstanding 4 psi, but would suffer major damage in an operating mode.

Type C Plants

Plants that contain large numbers of wooden structures are probably somewhat more resistant to fire ignition than Type A plants, since there probably is a smaller fraction of kindling fuel. But even so, at the 10 psi level, it would seem likely that a significant fire hazard exists.

EXPEDIENT COUNTERMEASURES FOR EXTERNAL FIRE HAZARD

The only practical expedient countermeasures are to move the equipment out of the expected fire zone--this could mean in some cases moving it completely off-site--or to cover it with soil or other fire resistant material.

EXPEDIENT COUNTERMEASURES FOR INTERNAL FIRE HAZARD

Type A Plants

Remove all combustible material to a secure storage area remote from the plant proper. Necessary separation distances are those given under the "Residential" column in Table A-2.

Type B Plants

Shut down plant as described in main section. Also reduce quantities of fuel stored to an amount that can be contained in the spill volume.

Type C Plants

Remove equipment from plant area in cases of plants involving numerous combustible structures, or remove combustible structures.

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Washington, D.C. 20234

Mr. Samuel Kramer, Chief
Office of Federal Building Technology
Center for Building Technology
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Washington, D.C. 20234

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Box 5800
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Scientific Service, Inc.
35 Arch Street
Redwood City, CA 94062 (2)

Mr. Richard Laurino
Center for Planning and Research
560 San Antonio Rd, Suite 105
Palo Alto, CA 94306

Mr. Fred Sauer
Physics International Company
2700 Merced Street
San Leandro, CA 94577

The Dikewood Corporation
1613 University Blvd, N.E.
Albuquerque, NM 87102

Mr. Leo A. Schmidt
Institute for Defense Analyses
Program Analysis Division
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Dr. William Chenault
Human Sciences Research, Inc.
Westgate Industrial Park
7710 Old Springhouse Road
McLean, VA 22102

Mr. Raymond Alger
SRI International
333 Ravenswood
Menlo Park, CA 94025

Research Triangle Institute
Attn: Edward L. Hill
P.O. Box 12294
Research Triangle Park,
North Carolina 22709 (2)

Mr. Walmer Strope
Center for Planning and Research
5600 Columbia Pike - Suite 101
Bailey's Crossroads, VA 22041

H.L. Murphy Associates
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BDM Corporation
1801 Randolph Road, S.E.
Albuquerque, NM 87106

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Senior Scientist
Science Applications, Inc.
1710 Goodridge Drive
P.O. Box 1303
McLean, VA 22101

Stan Martin & Associates
860 Vista Drive
Redwood City, CA 96062

Bell Telephone Laboratories
Attn: Mr. E. Witt
Whippany Road
Whippany, NJ 07981

Dr. Ben Sussholz
R1/2094
TRW
One Space Park
Redondo Beach, CA 90278

Dr. Joseph E. Minor, Director
Institute for Disaster Research
Department of Civil Engineering
Box 4089
Lubbock, TX 79409

Dr. Michael A. Pachuta
4563 Braeburn Drive
Fairfax, VA 22032

Mr. Donald A. Bettge
8807 Lakehill Drive
Lorton, VA 22079

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EVALUATION OF PRODUCTION PROCESSES TO IDENTIFY ESSENTIAL EQUIPMENT

Unclassified

June 1986

Scientific Service, Inc., Redwood City, CA
Contract EMW-84-1729, Subcontract 62X-05923C

246 pages

The report describes a method to identify items of equipment essential to industrial processes, rank their relative importance, assess their vulnerabilities to critical damage mechanisms common among hazards, and tie this to a single index. The method is formatted as worksheets for industry to select countermeasures to enhance physical and economic survival in a major disaster.

An assessment of the procedure applied to nuclear attack is described. Both technical and practical aspects are addressed, and testing of both aspects are discussed. Notwithstanding gaps identified in technical knowledge for protecting industrial equipment from a nuclear attack, and recommendations for experiments to fill these gaps, the procedure appears workable; three case histories address the identification of essential equipment, assessment of its vulnerability, establishment of the threat magnitude to use for planning, and identification of suitable countermeasures. With addition of threat and magnitude for other hazards, the procedure appears suitable for multi-hazards application.

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